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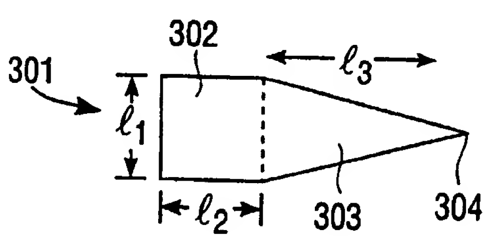

(57) Abstract: An interconnect assembly and methods for making and using the assembly. An exemplary embodiment of an aspect of the invention includes a contact element which includes a base portion adapted to be adhered to a substrate and a beam portion conencted to and extending from the base portion. The beam portion is designed to have a geometry which substantially optimizes stress across the beam portion when deflected (e.g. it is triangular in shape) and is adapted to be freestanding. An exemplary embodiment of another aspect of the invention involves a method for forming a contact element. This method includes forming a base portion to adhere to a substrate of an electrical assembly and forming a beam portion connected to the base portion. The beam portion extends from the base portion and is designed to have a geometry which substantially evenly distributes stress across the beam portion when deflected and is adapted to be freestanding. It will be appreciated that in certain embodiments of the invention, a plurality of contact elements are used together to create an interconnect assembly. Interconnect assemblies having resilient contact elements and methods for making these assemblies. In one aspect, the interconnect assembly includes a substrate and a resilient electrical contact element disposed on the substrate. A first portion of the resilient contact structure is disposed on the substrate and a second portion extends away from the substrate and is capable of moving from a first position to a second position under the application of a force. A stop structure is disposed on the surface of the substrate and on a surface of the first portion of the resilient contact structure. According to another aspect of the present invention, a beam portion of the resilient contact structure has a substantially triangular shape.

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INTERCONNECT ASSEMBLIES AND METHODS

FIELD OF THE INVENTION

The present invention relates to interconnect assemblies and methods for making and using interconnections and methods for making these interconnect assemblies.

BACKGROUND OF THE INVENTION

There are numerous interconnect assemblies and methods for making and using these assemblies in the prior art. Interconnect assemblies for making electrical interconnections with semiconductor integrated circuits must support the close spacing between interconnect elements, sometimes referred to as the pitch of the interconnect elements. Certain interconnect assemblies perform their functions through testing and the useful life of the integrated circuit. One type of interconnect assembly in the prior art uses a resilient contact element, such as a spring, to form either a temporary or a permanent connection to the contact pads on a semiconductor integrated circuit. Examples of such resilient contact elements are described in U.S. Patent 5,476,211 and also in co-pending U.S. Patent Application entitled "Lithographically Defined Microelectronic Contact Structures," Serial No. 09/032,473, filed February 26, 1998, and also co-pending U.S. Patent Application entitled "Interconnect Assemblies and Methods," Serial No. 09/114,586, filed July 13, 1998. These interconnect assemblies use resilient contact elements which can resiliently flex from a first position to a second position in which the resilient contact element is applying a force against another contact terminal. The force tends to assure a good electrical contact, and thus the resilient contact element tends to provide good electrical contact.

These resilient contact elements are typically elongate metal structures which in one embodiment are formed according to a process described in U.S. Patent 5,476,211. In another embodiment, they are formed lithographically (e.g. in the manner described in the above-noted patent application entitled "Lithographically Defined Microelectronic Contact Structures"). **Figure 1A** illustrates an example of resilient contact elements which are formed using a technique described in U.S. Patent 5,476,211. **Figure 1B** shows an example of a resilient contact element which is formed using lithographic techniques such as

those described in the above-noted U.S. Patent Application entitled "Lithographically Defined Microelectronic Contact Structures." In general, resilient contact elements are useful on any number of substrates such as semiconductor integrated circuits, probe cards, interposers, and other electrical assemblies. For example, the base of a resilient contact element may be mounted to a contact terminal on an integrated circuit or it may be mounted onto a contact terminal of an interposer substrate or onto a probe card substrate or other substrates having electrical contact terminals or pads. The free end of each resilient contact element can be positioned against a contact pad on another substrate to make an electrical contact through a pressure connection when the one substrate having the resilient contact element is pressed towards and against the other substrate having a contact element which contacts the free end of the resilient contact element.

It will be appreciated that in certain instances, it may be desirable to secure the free end to the corresponding contact element by an operation such as soldering. However, in many instances, it is appropriate to allow the contact to be made by pressure between the two substrates such that the contact end of the resilient contact element remains free.

The resilient contact elements are useful for making electrical contacts because their resilience maintains pressure for good electrical contact and because they allow for tolerance in the vertical or Z direction such that all contact elements will be able to make a contact even if their heights vary slightly. However, this pressure sometimes leads to the deformation or degradation of resilient contact elements as they are compressed too much in the vertical direction. One approach to prevent the deformation or degradation of such resilient contact elements is to use a stop structure on one of the two substrates. The stop structure effectively defines the maximum deflection of the resilient contact element such that each of the resilient contact elements is prevented from overflexing (undue deflection) or being destroyed as a result of the two substrates being pressed toward each other. **Figure 1A** shows an example of an integrated circuit having contact pads 103 and having, for each of the contact pads, a resilient contact element 110 mounted thereto. A plurality of stop structures 104 and 105 are disposed on the surface of the integrated circuit 102. These stop structures will prevent undue deflection and

may engage another substrate which is pressed towards the surface of the semiconductor integrated circuit 102.

Figure 1B shows an example of a lithographically defined resilient contact element on a substrate, such as a semiconductor integrated circuit 120. The integrated circuit includes on its surface a stop structure 150.

The lithographically defined resilient contact structure of **Figure 1B** includes an intermediate layer 123 which makes an electrical interconnection with the bonding pad 122 through an opening in the passivation layer 121 on the surface of the substrate of the integrated circuit 120. A first metal layer 125 and a second metal layer 126 are then formed to create a beam having a step 128 and a beam portion 127. In this example, the beam portion is substantially parallel to the surface of the substrate 120. A tip structure including components 181, 182, 183, 184, and 185 is then subsequently mounted to the end of the beam 127 to create a resilient contact structure. Further details concerning methods for creating and using such lithographically defined resilient contact structures are described in the co-pending U.S. Patent Application entitled "Lithographically Defined Microelectronic Contact Structures" which is referred to above and which is hereby incorporated herein by reference. While this lithographically defined resilient contact element provides the advantage that it can be formed lithographically using modern photolithographic techniques which are prevalent in the semiconductor industry, there are certain disadvantages with this type of resilient contact element. For example, when a force F as shown in **Figure 1B** is applied downwardly against the tip 185, a torqueing action occurs at the base of the resilient contact element. This torqueing action results from the pressure contact which occurs when a contact element on another substrate is pressed towards the tip 185. This torque at the base tends to place stress at the base and along the beam portion. If the beam portion 127 is a rectangular shape, this results in the stress being localized at the portion of the beam which is next to the base of the resilient contact element. While the stop structure 150 provides some assurance that certain levels of stress will not be exceeded, there are still certain concentrated areas of stress, as a result of the rectangular shape, which must be accounted for when designing a resilient contact element. Typically, accounting for these concentrated areas of stress requires increasing the use of the amount of materials at certain points in the resilient contact element. This in turn may limit

the ability to design resilient contact elements to be smaller. This is particularly undesirable as the sizes of structures on semiconductor integrated circuits are being reduced over time.

Thus, it is desirable to provide an improved resilient contact element.

SUMMARY OF THE INVENTION

The present invention provides an interconnect assembly and methods for making and using the assembly. An exemplary embodiment of an aspect of the invention includes a contact element which includes a base portion adapted to be adhered to a substrate and a beam portion connected to and extending from the base portion. The beam portion has a beam geometry which is chosen to optimize stress. The beam portion is in one embodiment substantially triangular in shape and is adapted to be freestanding.

An exemplary embodiment of another aspect of the invention involves a method for forming a contact element. This method includes forming a base portion to adhere to a substrate of an electrical assembly and forming a beam portion connected to the base portion. The beam portion has a beam geometry which is chosen to optimize stress. The beam portion extends from the base portion and is in one embodiment substantially triangular in shape and is adapted to be freestanding.

In another example of the present invention, a resilient electrical contact element includes a base portion which is attached to a substrate and a beam portion which is connected to and extends from the base portion. The beam portion is adapted to be free-standing and has a beam geometry which is selected to produce a substantially optimized stress parameter given a desired size constraint of the beam portion and a desired spring constant (e.g. spring rate) for the resilient contact element. In one embodiment of this example, the geometry is selected to improve performance of the resilient contact element over a cantilever beam which has a substantially constant cross-sectional area. The performance may be improved by, for example, substantially evenly distributing stress throughout the beam when it is deflected.

It will be appreciated that in certain embodiments of the invention, a plurality of contact elements are used together to create an interconnect assembly.

Various other assemblies and methods are also described below in conjunction with the following figures.

The present invention provides an interconnect assembly and methods for making and using the assembly. In one example of the present invention, an interconnect assembly includes a substrate and a contact element disposed on the substrate. A first portion of the contact element is adapted to be free-standing and is further adapted to be capable of moving from a first position to a second position when a force is applied to the first portion of the contact element. The interconnect assembly further includes a stop structure which is disposed on a second portion of the contact element. The stop structure defines in part the second position of the contact element. In one particular exemplary embodiment of the present invention, the substrate comprises a semiconductor integrated circuit. Force is applied when another contact element is brought into mechanical and electrical contact with the contact element. The stop structure defines the second position which defines a maximum flexing of the contact element.

According to another example of the present invention, an interconnect assembly is formed by a method of disposing a contact element on a substrate, where a first portion of the contact element is free-standing and is capable of moving from a first position to a second position when a force is applied to the first portion of the contact element. The method also includes disposing a stop structure on a second portion of the contact element, where the stop structure defines the second position.

It will be appreciated that a plurality of contact elements of the invention may be used to create an interconnect assembly.

An example of a method according to another aspect of the present invention involves the formation of a freestanding elongate resilient contact element using a mold. In this method, a mold is depressed into a deformable material; the mold determines a shape of at least a portion of the freestanding elongate resilient contact element. This portion of the freestanding elongate resilient contact element is then formed on the deformable material.

Various other assemblies and methods are described below in conjunction with the following figures.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements.

Figure 1A shows an example of a plurality of resilient contact elements disposed on a substrate with stop structures on that substrate. **Figure 1A** is a perspective view of the substrate 102 with its resilient contact elements and stop structures.

Figure 1B shows an example of a lithographically formed resilient contact element formed on a substrate with a stop structure. **Figure 1B** is a cross-sectional view of the resilient contact element and the stop structure.

Figure 2A is a cross-sectional view of a resilient contact element according to one embodiment of the present invention.

Figure 2B is a cross-sectional view of another embodiment of a resilient contact structure of the present invention with a stop structure disposed over a base of the resilient contact element.

Figure 2C shows a cross-sectional view of another example of an embodiment of a resilient contact element according to the present invention in which a stop structure is disposed over a base of the resilient contact element.

Figure 2D shows a cross-sectional view of another example of a resilient contact element of the present invention.

Figures 2E, 2F, 2G, and **2H** show cross-sectional views which compare the deflection of an initially straight resilient contact element, shown in **Figure 2E,** to the deflection of an initially curved resilient contact element shown in **Figure 2G.**

Figure 3A is a top view of one example of a resilient contact element according to the present invention. **Figure 3B** is a top view of another example of a resilient contact element according to the present invention. **Figure 3C** is a top view of another example of a resilient contact element according to the present invention. **Figure 3D** shows, in top view, an array of resilient contact elements disposed on a substrate.

Figure 4 shows, in cross-sectional view, an example of an interconnect assembly of the present invention which includes a resilient contact element having a stop structure disposed over the base of the contact element and **Figure 4** also

shows another substrate being brought into contact with the substrate carrying the stop structures and the resilient contact element.

Figure 5 is a flowchart showing an example of a method for forming a resilient contact element and a stop structure according to one embodiment of the present invention.

Figure 6A shows a cross-sectional view of the structure of an interconnect assembly during the formation of a resilient contact element according to one method of the present invention.

Figure 6B shows another cross-sectional view at a later processing stage in the fabrication process which produces a resilient contact element according to one embodiment of the present invention.

Figure 6C shows a top view of a portion of the structure 608 shown in **Figure 6B**.

Figure 6D shows a cross-sectional view of the structure which results after several processing steps shown in **Figure 5**.

Figure 6E shows a cross-sectional view of an alternative substrate onto which a resilient contact element of the present invention may be formed.

Figure 6F shows a cross-sectional view after certain processing steps in the method of **Figure 5**.

Figure 6G shows another cross-sectional view after further processing steps of the method of **Figure 5**.

Figure 6H shows a top view of a portion of the structure shown in **Figure 6G**.

Figure 6I shows another cross-sectional view of the structure being formed according to the method shown in **Figure 5**.

Figure 6J shows another cross-sectional view of a resilient contact element as it is being formed according to the method shown in **Figure 5**.

Figure 6K shows a further cross-sectional view after further processing steps according to the method of **Figure 5**.

Figure 6L shows a top view according to one embodiment of the structure shown in **Figure 6K**.

Figure 7A shows in cross-sectional view an embodiment with multiple resilient contact elements and their corresponding stop structures.

Figure 7B shows a perspective view of one resilient contact element disposed within a well formed by the contact structure according to one exemplary embodiment of the present invention.

Figure 8A shows an alternative embodiment in cross-sectional view of a resilient contact element according to the present invention.

Figure 8B shows in perspective view the resilient contact element of **Figure 8A** after the element has been assembled.

Figures 9A, 9B, 9C and **9D** show cross-sectional views of a substrate during another method, according to the invention, for forming a resilient contact element.

DETAILED DESCRIPTION

The present invention relates to interconnection assemblies and methods and particularly to interconnect assemblies and methods for making mechanical and electrical connection to contact elements on an integrated circuit. The following description and drawings are illustrative of the invention and are not to be construed as limiting the invention. Numerous specific details are described to provide a thorough understanding of the present invention. However, in other instances, well known or conventional details are not described in order to not unnecessarily obscure the present invention in detail.

Figure 2A shows a cross-sectional view of a resilient contact element which is one example of an embodiment of the present invention. The resilient contact element 201 of **Figure 2A** includes a first metal layer 209 and a second metal layer 210 which have been formed at an oblique angle relative to the surface of the substrate 202. The first metal layer 209 may be selected for its resiliency properties in order to impart resiliency to the resilient contact element and the second metal layer 210 may be selected for its electrical conductivity properties in order to provide good electrical conductivity for the resilient contact element. The substrate 202 is typically a semiconductor substrate which includes an integrated circuit which includes various terminals, one of which is shown as the contact pad 207 in **Figure 2A**. Representative terminals carry input/output signals, power or ground. This contact pad 207 is coupled through a wiring layer 206 to internal circuitry within the integrated circuit. The wiring layer 206 is disposed within an insulating layer 204, and layers 206 and/or 204 may be covered by a passivating

layer 205 on the top surface of the substrate 202. The layer 203 may be an insulating layer or a polysilicon layer or other layers which are known and used in integrated circuits. The contact pad 207 is electrically and mechanically coupled to a shorting layer 208 which is disposed above the contact pad 207. The metal layers 209 and 210 are formed above the shorting layer 208 with a base portion of each of the metal layers 209 and 210 above and electrically connected to contact pad 207. Electrical conductivity between the contact pad 207 occurs through the shorting layer 208 and the metal layer 209 and finally to the metal layer 210. It will be appreciated that the resilient contact element 201 of **Figure 2A** may also be used for other types of interconnect assemblies such as probe card assemblies or interposers or other connection systems where a resilient contact element may provide electrical conductivity from a conductor in the substrate 202 to the tip, which is free-standing, of the resilient contact element 201. As can be seen from **Figure 2A**, this resilient contact element is both free-standing and elongate. Also, the resilient contact element, in the embodiment shown in **Figure 2A**, is sloped relative to the surface of the substrate 202. In a preferred embodiment, this slope typically forms an oblique angle relative to the surface of the substrate 202.

In one particular embodiment of the present invention, the resilient contact element 201 may be formed such that the beam portion which extends from the base has a substantially triangular shape. This is shown in the top view of the resilient contact structure 301 shown in **Figure 3A**. That is, the beam portion 215 of the resilient contact element 201 may be formed in such a way as to have a substantially triangular shape such as the beam portion 303 of the resilient contact element 301 shown in **Figure 3A**. The resilient contact element 301 includes a base 302 which is attached to the beam portion and a tip 304 which makes electrical contact with another interconnect terminal/pad. **Figure 3B** shows, in a top view, another example of a resilient contact element 301A which has a beam portion 303A which has a substantially triangular shape. The beam portion 303A is attached to the base 302A and includes a tip 304A.

Figure 2B shows another embodiment of the present invention in which a stop structure 211 is disposed on the top surface of the substrate 202 and is also disposed on top of a portion of the base 214 of the resilient contact element 212. In this embodiment shown in **Figure 2B**, the substrate 202 includes the similar components 203, 204, 205, 206, 207, 208, 209 and 210 as in the case of the

interconnect assembly shown in **Figure 2A**. A resilient contact element 212 includes two metal layers 209 and 210 which have been formed such that a base portion 214 of both metal layers rests on the upper surface of the shorting layer 208 while beam portion 215 extends from an end of the base portion 214 at an oblique angle relative to the surface of the substrate 202. The beam portion of the resilient contact element 212 may have a triangular shape or other shapes such as rectangular shapes or other shapes which are known to be used for resilient contact elements. In one embodiment, however, it is preferred that the beam 215 have a triangular shape such as the beam 303 of **Figure 3A** or beam 303A of **Figure 3B**. The stop structure 211 is formed over the base portion 214 of the resilient contact element 212. The stop structure 211 acts to prevent overflexing (e.g. undue deflection) of the resilient contact element by determining the maximum amount of deflection of the resilient contact element 212 as it is pressed by a force F towards the surface of the substrate 202. When another contact element, such as a contact pad on another substrate, is pressed toward and against the tip 216 of the resilient contact element 212, the upper surface of the stop structure 211 will engage a corresponding surface of the other substrate to prevent the substrate from being pressed further towards the surface of the substrate 202. That is, the travel between the two substrates is limited by the stop structure 211 such that the stop structure 211 will define or determine a minimum distance between the substrates and hence a maximum flexing of the resilient contact element 212. Further details in connection with advantages of and uses of stop structures are described in co-pending U.S. Patent Application Serial No. 09/032,473, which was filed July 13, 1998 and is entitled "Interconnect Assemblies and Methods;" this co-pending patent application entitled "Interconnect Assemblies and Methods" is hereby incorporated herein by reference.

Figure 2C shows a simplified example of a resilient contact structure with a stop structure according to one exemplary embodiment of the invention. The interconnect assembly 231 includes a substrate 232 which has a wiring layer 237 embedded therein. The wiring layer 237 is electrically coupled to a base portion 235 of a resilient contact element 234. The base portion 235 is coupled to the beam portion 236. Typically, as described below, the beam portion 236 and the base portion 235 are formed integrally in one operation. Both the base portion 235 and the beam portion 236 may contain multiple conductive layers such as the

layers 208, 209, and 210 as shown in **Figures 2A** and **2B**. As in the case of the embodiments shown in **Figures 2A** and **2B**, the beam portion 236 of the resilient contact element 234 extends from an end of the base portion 235 at an oblique angle relative to the surface of the substrate 232. The stop structure 233 is disposed above and adhered to the surface of the substrate 232 and it is also disposed above and adhered to the top surface of the base portion 235. As shown in **Figure 2C**, an end of the wiring layer 237 is mechanically adhered to and electrically coupled to the base portion 235. Since the stop structure 233 is mechanically adhered to the top surface of the substrate 232 and to the top surface of the base portion 235, any torque created at the base portion 235 (e.g. as a result of a force exerted against the tip of the beam portion 236 when a contact pad, such as the contact pad 411 shown in **Figure 4**, is pressed towards the surface of the substrate 232) will be balanced through various parts of the entire structure, including the stop structure 233, rather than merely the base portion 235 and the beam portion 236. It will be appreciated that, in an alternative embodiment, a stop structure may be disposed on only the base portion 235 and not the substrate 232 and that this stop structure will tend to balance any torque created at the base portion.

Several dimensions are labeled in **Figure 2C** and also **Figure 3A** in order to provide examples of the present invention. It will be appreciated that the following examples are merely illustrative of the invention and are not intended to limit the invention and are not intended to provide an exhaustive set of examples for possible structures which are within the scope of the present invention. The distance *c* represents in one example (e.g. see **Figure 4**) the maximum displacement or deflection of the resilient contact element. In one example, this is approximately 75 microns (about 3 mils). This distance *c* is normally less than the element's compliance which is the total amount of deflection or flexing which is available before "failure" of the resilient contact element. This distance in one example (e.g. see **Figure 4**) represents the travel of the tip from a point where there is no force pressing against the tip to the point where the tip has been pressed flush with the top surface of the stop structure 233. Examples of these two states are shown in **Figure 2C** where no force is being applied to the tip and **Figure 4** where a force has been applied to the tip such that one substrate 410 has its surface virtually in contact with the top surface of the stop structures 406 and 407.

The thickness *t* represents the total thickness of the resilient contact element in a perpendicular cross-section of the resilient contact element as shown in **Figure 2C**. Typically, this thickness will be approximately the same throughout any particular cross-section, although it will be appreciated that in alternative embodiments, this thickness may be different at certain cross-sections. It will also be appreciated that **Figure 2C** represents a simplified example of a resilient contact element 234 and that the base and the beam portions may be fabricated from one or more conductive layers. In a typical embodiment, the thickness is approximately 25 microns, and the total height *h* of the resilient contact element 234 is approximately 150 microns (about 6 mils).

For certain embodiments, the spring rate of the resilient contact element may be approximately 1 to 2 grams per mil, where the spring rate "k" represents the force of the spring divided by the displacement of the spring ($k = F/x$). It will be appreciated that once the geometry and the materials have been selected for a particular resilient contact element, the thickness of the spring generally determines the spring rate. Thickness is a major factor in determining the stress at a maximum deflection, which is also dependent upon the material in the resilient contact element. It will be appreciated that certain design points or goals will be established for a resilient contact element such that the maximum possible stress for the resilient contact element is less than a desired amount. The use of the stop structure 233 will tend to control the maximum amount of stress and also tend to relieve the stress at maximum deflection by counteracting the torque at the base portion of the resilient contact element. This can be seen from **Figure 4** which will be further described below.

The resilient contact element may have a curved shape which provides certain advantages that are described here in conjunction with **Figures 2D, 2E, 2F, 2G** and **2H**. **Figure 2D** shows a cross-sectional view of a curved resilient contact element 234A which includes a base portion 235A, a tip 239A and a curved beam portion 236A. The base portion 235A is coupled electrically to the wiring layer 237. The curvature of the beam portion may be used to compensate for bending of the beam portion during deflection of the resilient contact element. This compensation is shown in the comparison shown by **Figures 2E, 2F, 2G** and **2H**.

A stop structure 233 is disposed on the base portion 235A and (optionally) on the substrate 232.

Figures 2E and **2F** respectively show an initially straight resilient contact element before and after deflection of the resilient contact element. When a force F is applied to the tip of the beam portion 236, the beam portion curves as shown in **Figure 2F**, and this causes the tip to be tilted away from the surface of the contact point on the other substrate and causes a shallow angle θ_1 to be formed between a line representing the surface of the contact point and a line through the end of the beam portion. These lines are shown in **Figure 2F** along with the angle θ . The shallowness of this angle tends to be undesirable for making a good electrical connection.

Figures 2G and **2H** respectively show an initially curved resilient contact element before and after deflection of the resilient contact element. When the force F is applied to the tip of the beam portion 236A, this beam portion tends to be straightened out as shown in **Figure 2H**. As a result of this straightening out, the angle θ_2 (the angle between the line representing the surface of the contact point and a line through the end of the beam portion) is not as shallow as angle θ_1 and thus better electrical contact may be accomplished using the curved resilient contact element.

Figure 3A and **Figure 3B** show another aspect of the present invention in which the beam portion of the resilient contact element has a substantially triangular shape. The resilient contact element 301 includes a base 302 which corresponds to the base 235 in **Figure 2C**. The beam portion 303 shown in the top view of **Figure 3A** corresponds to the beam portion 236 of **Figure 2C**. The beam portion 303 includes a tip 304 which corresponds to the tip 239 of the resilient contact element 234 of **Figure 2C**. The triangular shape of the beam portion 303 tends to more evenly distribute across (e.g. tip to base) the entire beam the stress created when the tip 304 is pressed towards the surface on which the base 302 is resting. This allows the use of less material in the beam 303 while still obtaining good performance for the resilient contact element, such as the ability to withstand continued stress throughout the useful life of the resilient contact element. **Figure 3B** shows an alternative triangular shaped resilient contact element.

Figure 3C shows, in top view, another example of a resilient contact element 310 which has a substantially triangular shape. In this case, the triangle is modified at the electrical contact end 312 to include a portion of a rectangle. The beam portion of the resilient contact element 310 is normally free-standing and capable of deflections when depressed and includes a triangular part 314 and a rectangular part 312. The triangular part is attached to the base portion 316. The beam portion may be attached to the base portion 316 at an oblique angle and may be lithographically formed together with the base portion 316. It can be seen that the cross-sectional areas taken at different cross-sections 318 and 320 will be different, and this is also true of the contact elements 301 and 301A.

The geometry of the beam portions of these substantially triangular shaped resilient contact elements provides improved performance over a cantilever beam spring which has a substantially constant cross-sectional area. Other shapes may also be selected to provide improved performance relative to cantilever beam springs which have substantially constant cross-sectional areas. The substantially triangular shape gives better behavior of the spring under stress and allows for tighter packing (small pitches) for the springs. **Figure 3D** shows an array of tightly packed (e.g. pitch of 10 microns) resilient contact elements 310A, 310B, 310C and 310D of the type shown in **Figure 3C** on a substrate 322 (which may be an integrated circuit or an electrical connection substrate which may be used to test or make permanent contact to an integrated circuit). The geometry of the beam portion is selected to give optimum stress behavior for a given size constraint (e.g. the size as determined by the packing of the contact elements) and a given spring rate and a given/desired amount of compliance for the contact element. A smaller size, as determined by a size constraint, for a given spring rate and given compliance tends to place greater stress at certain points of a cantilever beam having a constant cross-sectional area. A substantially triangular shaped resilient contact element, on the other hand, allows for tighter packing (see, e.g. **Figure 3D**) and smaller sizes while, for the same spring rate and given compliance, allowing better behavior under stress.

In a typical embodiment, the dimensions l_1 and l_2 are about 9 mils while the dimension l_3 is about 27 mils. An array of these resilient contact elements may be formed on a substrate, such as an integrated circuit or a contactor for making contact to an integrated circuit, to create a densely packed array of such resilient

contact elements. **Figure 8B** shows one example of a layout of an array on a substrate 803. In one embodiment, these resilient contact elements may be packed so densely that the distance between corresponding points (e.g. bases) on adjacent contact elements is less than 30 mils and even as small as 0.1 mils (approximately 2.5 microns). **Figure 3D** shows another example of an array of densely packed (tight pitch) resilient contact elements.

The actual use of an interconnect assembly according to one embodiment of the present invention will now be described while referring to **Figure 4**. The substrate 402 includes a resilient contact element 403 having a beam portion 405 and a base portion 404. In this particular embodiment, the beam portion 405 may have a triangular shape or may have another shape such as a rectangular shape. Two stop structures 406 and 407 are adhered to the upper surface of the substrate 402 and the stop structure 406 is also adhered to the top portion of the base 404. The base 404 makes mechanical and electrical contact with the wiring layer 415 in the substrate 402. It will be appreciated that the substrate 402 may be a semiconductor integrated circuit or may be a passive wiring layer such as a probe card or interposer structure. Another interconnection assembly 410 having a contact pad 411 is brought into electrical and mechanical contact with the tip of the beam portion 405 as shown in **Figure 4**. The entire assembly 401, which includes substrates 410 and 402, is pressed together to assure a good pressure connection between the tip of the beam portion 405 and the surface of the contact pad 411. The contact pad 411 makes electrical contact with other components through the wiring layer 412 of the substrate 410. As the substrate 410 is pressed towards the substrate 402, the tip of the beam portion 405 makes a wiping action which occurs laterally along the direction of the arrow 413 as shown in **Figure 4**. This improves the electrical contact between the beam portion 405 and the pad 411, thus improving the electrical contact between the wiring layers 415 and 412. It will be appreciated that **Figure 4** illustrates the circumstance where the substrate 410 is pressed completely against the substrate 402 and thus no further "travel" is possible (they cannot get closer). This represents the maximum deflection of the resilient contact element 403. However, in use of the assembly 401, the two substrates may not be abutting such that the resilient contact element 403 is deflected less than the maximum deflection while still achieving acceptable electrical conductivity between the beam 405 and the pad 411. The final assembly

of substrates 402 and 410 may be held in place by various techniques (with either maximum deflection of the resilient contact elements or less than maximum deflection) including by mechanical forces (e.g. F_m shown in **Figure 4**) and/or by an adhesive applied between the surface of substrates 402 and 410 (not shown).

A method of fabricating an interconnect assembly will now be described; this method represents one particular example of the present invention and it will be appreciated that various other methods may be employed using alternative techniques and procedures. The method 500 shown in **Figure 5** begins with the operation 502. This particular method assumes that a redistribution layer will be applied in order to redistribute contact pads having a certain arrangement and geometry to a set of another contact pads having a different arrangement and/or geometry. It will be appreciated that in other circumstances, a redistribution layer may not be necessary, and the contact elements of the invention may terminate directly on the wiring layers of the substrate without a redistribution layer; see **Figure 6E**. In operation 502, a passivation layer, such as a polyimide layer, is applied to the upper surface of the substrate having a contact pad disposed on the upper surface. In one embodiment, a polyimide layer may be spun onto the upper surface to uniformly cover the surface. Then the passivation layer is patterned using conventional photolithography to create openings in the passivation layer over the contact pads at the surface of the substrate. These contact pads may be input/output interconnections in a semiconductor integrated circuit or they may be contact terminals on a passive or active board or substrate such as a probe card or an interposer or other interconnect assemblies.

Figure 6A shows an example of an interconnect assembly 601 having a contact 604 at the upper surface of the substrate 602. A wiring layer 603 is disposed in the substrate 602 in order to provide electrical conductivity between the pad 604 and another component, such as a circuit within the substrate 602 or a contact terminal at another location on the substrate 602. It will be appreciated that typically the wiring layer 603 is disposed within an insulating layer in the substrate 602. It will also be appreciated that the portion shown in **Figure 6A** is the upper portion of the substrate 602 and that other wiring layers and/or circuitry is disposed below this portion shown in **Figure 6A**. The passivation layer applied in operation 402 is shown as passivation layer 605 in **Figure 6A**. This

passivation layer has been patterned to create an opening 606 over the contact pad 604.

In operation 504 of **Figure 5**, a shorting layer is applied over the surface of the passivating layer 605 and over the surface of the contact pad 604. Then, a conventional photoresist is applied over the entire surface of the shorting layer and this photoresist is patterned using conventional photolithography to create an opening over the shorting layer. The shorting layer may be formed from copper, titanium, or titanium/tungsten or other appropriate metallization and may be sputtered onto the surface of layer 605. An example of a resulting interconnect assembly after operation 504 is shown in **Figure 6B**. The interconnect assembly 608 of **Figure 6B** includes a shorting layer 609 which is disposed above the passivation layer 605 and the contact pad 604. The contact pad and the shorting layer 609 are in electrical conductivity. The patterned photoresist layer 610 includes an opening 611 over a portion of the shorting layer. This opening will be used to create a redistribution layer wherein the layout of the contact pad 604 will be redistributed to another location. This may be done to relax the interconnection pitch achieved at the end of the process when the resilient contact elements have been formed on the substrate 602. **Figure 6C** shows a top view of the redistribution wiring layer. In particular, **Figure 6C** shows the pattern in the photoresist layer 610 which has created a hole in the patterned photoresist 610. This hole exposes a portion of the shorting layer 609 as shown in **Figure 6C**.

In operation 506 of **Figure 5**, a redistribution layer is applied over the shorting layer. This redistribution layer may be applied by electrolytically plating (or electroless plating) a metal layer (e.g. copper or gold) onto the exposed portion of the shorting layer, where the shorting layer is used as the cathode in an electrolytic plating operation. It will be appreciated that on a typical substrate there will be many such redistribution traces created on the surface of the substrate in each of the patterned openings in the patterned photoresist 610.

After the redistribution layer has been applied, the patterned photoresist layer 610 is removed and the shorting layer which is exposed after removing the patterned photoresist layer is also removed. The redistribution layer may be used as a mask to remove the shorting layer. Thus, in this case, typically one metal (e.g. Ti/W) will be used to create a shorting layer and another metal (e.g. Cu) will be used to create the redistribution layer such that the redistribution layer will

remain intact while the shorting layer is etched away or removed under the action of a solvent or etching agent which is resisted by the redistribution layer metal. The result of operation 506 is shown in **Figure 6D**. It can be seen that the patterned photoresist layer 610 has been removed and that the unprotected portion of the shorting layer 609 has also been removed, leaving the structure of the interconnect assembly 614 shown in **Figure 6D**. In an alternative embodiment in which the shorting layer 609 is required for subsequent electrolytic plating (e.g. because layer 642 has electrically isolated regions due to openings in the layer), then the shorting layer 609 is not removed in operation 506 but is removed in operation 514.

It will be appreciated that operations 502, 504, and 506 have been used to create a plurality of redistribution traces, such as a redistribution layer, on the surface of the substrate 602. This may be required in certain cases where the contact pads were designed to be connected to an interconnect mechanism other than a resilient contact element or it may be desirable for other reasons. It will also be appreciated that in certain instances, no such redistribution layer is necessary and thus a resilient contact element may be fabricated on a via or other contact element on the surface of a substrate. An example of a via is shown in **Figure 6E** in which a post 623 of conductive material is exposed at the upper surface 622 of the substrate 621. This conductive post 623 is electrically coupled to the wiring layer 623 which is also in the substrate 621. Typically, the material encasing the wiring layer 624 and the post 623 is an insulating layer. The substrate 621 will typically be a part of a semiconductor integrated circuit although other interconnect assemblies may also be used, such as printed wiring substrates, interposers, etc. The processing from the structure 620 shown in **Figure 6E** is similar to the processing of the structure 614 shown in **Figure 6D** from steps 508 through 516 of **Figure 5**. That is, while the structure 620 does not need to be processed in operations 502, 504, and 506, it may be processed with operations 508, 510, 512, 514, and 516 as will structure 614 shown in **Figure 6D**.

The next operation in the method 500 is operation 508 in which a photoresist is applied and patterned to include an opening which has a slope on the photoresist. The resulting structure of the interconnect assembly is shown as structure 631 in **Figure 6F**. The photoresist 633 has been applied and patterned to create an opening 632 which has a slope 634 on a portion of the opening. The

opening is disposed at least partially over a portion of the conductive layer 615. It will be appreciated that typically, the flat portion of this opening will be utilized to construct a base for the resilient contact element while the sloped portion 634 will be used to construct the beam portion of the resilient contact element.

There are numerous techniques known in the art for creating openings in photoresist which include a slope on the photoresist. For example, a gray-scale mask having a relatively continuous gradient of opacity from clear to black may be used to create a slope on the photoresist. Other methods may be used to provide the tapered side wall, which include: gently reflowing the masking material to taper a side of the opening; controlling the light exposure intensity or time to the masking material; during exposure, varying the distance of the mask from the masking layer; exposing the masking layer two or more times, one through the mask having a small transparent area and separately with a mask having a larger transparent area; or combinations of these methods. Methods for forming an opening having a tapered side wall are further described in co-pending U.S. Patent Application entitled "Lithographically Defined Microelectronic Contact Structures" which has been referred to above and which is hereby incorporated herein by reference. Also described below is a method in which a mold is used to stamp a slope in a deformable material which is then used to form a resilient contact element.

After operation 508, the operation 510 involves applying a seed layer and then applying and patterning a photoresist layer to create a triangular opening (in one exemplary embodiment) for a resilient contact element. The seed layer 642 shown in **Figure 6G** may be applied by conventionally sputtering an appropriate metallic layer (e.g. Cu or Ti or Ti/W) onto the surface of the photoresist 633. If the shorting layer 609 was removed in operation 506, then the seed layer 642 should provide a continuous conductive surface except for the side wall 645, but if the shorting layer 609 was retained in operation 506, then the seed layer 642 may be electrically discontinuous over its entire surface.

In one preferred implementation, care is taken in the sputtering operation to avoid or prevent the sputtered material from remaining on the vertical side wall 645 so the opening in the photoresist 633 does not receive a continuous layer of the seed material. In another implementation, sputtering does cover some or all of the vertical side wall 645. In this implementation, it is generally preferable that the

subsequent masking and patterning step cover some or all of the sputtered side wall so as to minimize or prevent subsequent deposition of additional conductive materials on the vertical side wall.

After the seed layer 642 is applied, a photoresist layer is applied over the surface of the seed layer 642 as shown in **Figure 6G**. This photoresist layer is then patterned to create an opening 643 in the patterned photoresist layer 646 as shown in **Figure 6G**. This opening will be used to deposit at least one conductive layer, such as a metal layer, on the top of the exposed portion of the seed layer 642. This will include the deposition of a beam portion of the resilient element on the sloping portion 644 of the exposed portion of the seed layer 642. It is generally desirable for the subsequent plating or other deposition operation to fill the final shape contours in a regular manner. In one preferred embodiment, a seed layer is deposited so as to be primarily at the bottom of an opening in photoresist, particularly where the photoresist is from the masking and patterning phase of operation 510.

Figure 6G shows an example of a structure 641 after completion of the operation 510. **Figure 6H** shows a top view of a portion of the structure 641. In particular, the portion of the structure 641 over the opening 643 is shown in the top view of **Figure 6H**. It can be seen that the patterned photoresist layer 646 exposes only a portion of the seed layer 642. In the particular example shown in **Figure 6H**, the base portion of the resilient contact element will be formed in the rectangular portion of the exposed seed layer 642 and the beam portion of the resilient contact element will be formed in the triangular portion of the exposed seed layer 642. This will result in a resilient contact structure having a beam portion which is substantially triangular in shape, such as the resilient contact structure shown in **Figure 3A**. It will be appreciated that in other embodiments, other shapes, such as rectangular shapes, may be used for the beam portion and thus top views of such structures would look differently than **Figure 6H**.

After structure 641 has been created by completing the operation 510, operation 512 is performed on the structure 641 to achieve the structure 651 shown in **Figure 6I**. Operation 512 typically involves in one exemplary embodiment the electrolytic plating of a first metal layer and then a second metal layer into the triangular opening. In alternative embodiments, the opening may be a different shape (e.g. a rectangular shape to create a rectangular beam portion) and

alternative methods may be employed to deposit one or more conductive layers into the opening. The seed layer 642 (or a retained underlying shorting layer if the seed layer 642 is electrically discontinuous over its surface) will be used as the cathode in the electrolytic plating operation to plate the metal layers 652 and 653 onto the exposed portion of the shorting layer in the opening 643 as shown in **Figure 6I**. In one embodiment, the first metal layer 652 is selected to provide sufficient mechanical resiliency so that the final resilient contact element has sufficient resiliency for its intended operation. In one particular embodiment, a nickel cobalt alloy may be used. This alloy may be 70% nickel and 30% cobalt. This alloy may be heat treated as described in co-pending Application Serial Number 08/931,923 filed September 17, 1997. The second metal layer 653 is typically selected to provide good electrical conductivity; for example gold, or rhodium or a palladium cobalt alloy may be used. The composition of the various other layers and materials will be described further below. It will also be appreciated that numerous other types of materials may be selected for these metal layers, and these materials have been described in U.S. Patent 5,476,211.

After one or more conductive layers have been deposited into the opening 643 and the structure 651 has been completed, then operation 514 is performed to remove the photoresist layers and the sputtered shorting layers to achieve the structure 661 shown in **Figure 6J**. Conventional solvents or dry etching methods for removing or stripping the photoresist layers are utilized and solvents or etchants which will selectively remove the sputtered seed layer, such as seed layer 642, are used to remove the shorting layer. Thus, the patterned photoresist layer 646 and the patterned photoresist layer 636 is removed. Also, almost all of the seed layer 642 is removed except for the portion of the layer under the base of the resilient contact element 662 as shown in **Figure 6J**. This results in the structure shown in **Figure 6J** which then may be used as an interconnect assembly (without a travel stop structure) or may be used with a travel stop structure after such structure has been created in operation 516.

If it is desired to create a stop structure for the interconnect assembly, then step 516 is performed on the structure 661. This operation involves the application of a photo-imageable material (PIM), such as a negative photoresist such as SU8 which is commercially available, over the entire surface of the structure 661. It is desirable that this PIM be applied uniformly to a uniform

thickness and relatively flat, preferably as flat as possible. Thus it is preferred to spin the PIM, such as a photoresist, onto the surface of the structure 661. Care should be taken to apply enough photoresist material such that after it is spun on, it covers the base of the resilient contact element 662. That is, the height of the final structure created by this spun-on photoresist should be more than the height *h* of the base of the resilient contact element. Typically, the height of the final structure should also be less than the height of the freestanding contact point of the resilient contact element. Typically, the difference between the height of the freestanding contact point and the height of the final stop structure created by this photoresist should be fabricated to be the maximum deflection amount *c* described above.

After the proper amount of photoresist has been applied to achieve the desired height of the photoresist relative to the height *h* of the base of the resilient contact element (elements), then the photoresist layer is exposed and developed. The photoresist layer is exposed through a mask 690 such that an area around and below the beam portion of the resilient contact element remains unexposed while adjacent regions become exposed. Because the PIM in one embodiment is a negative photoresist, this will mean that the area which did not receive an exposure due to the mask 690 will be developed to remove the photoresist (and the exposed portions of the photoresist will remain), creating the opening 674 as shown in **Figure 6K**. In one embodiment, this mask 690 may be a rectangular mask which provides sufficient clearance for the beam portion to move up and down in the opening 674. In an alternative embodiment, the mask 690 may be a triangular mask which is designed to fit around the triangular shape of the beam portion of the resilient contact element when the resilient contact element has a triangular beam shape. Thus, the structure 671 shown in **Figure 6K** results from operation 516 and produces a stop structure 672 which is adhered to the passivation layer 605 and to the conductive layer 615 and to the base portions 652A and 653A of the resilient contact structure. Note that a portion 673 of the stop structure 672 is adhered to and is over the base portions 653A and 652A.

Figure 6L shows a top view of the structure shown in **Figure 6K**. **Figure 6L** assumes that the mask 690 had a triangular shape rather than a rectangular shape. Thus, the opening in the patterned photoresist 672 which forms the stop structure is a triangular opening which matches the shape of the triangular beam portion while providing sufficient clearance for the beam portion

to move up and down within the opening 674. The base 653a is shown underlying the travel stop structure 672 in **Figure 6L**. In an alternative embodiment, a rectangular mask 690a may be used over the beam portion in the exposure operation 516 to create a rectangular opening 674a shown in **Figure 7B**. This rectangular opening in the stop structure 672 may be used either for a triangular beam portion as shown in **Figure 7B** or may be used for a beam portion which is rectangular. It will be appreciated that whichever mask geometry is selected, it should provide sufficient clearance for the beam portion to move up and down within the opening in the stop structure 672.

Figure 7A shows a cross-sectional view of a plurality of resilient contact elements which include stop structures surrounding and disposed on the bases of the resilient contact elements.

Figure 8A shows an alternative embodiment for creating a resilient contact element which includes three portions, a base portion, a beam portion, and a contact portion. The contact portion is useful for contacting a second electronic component as described above in detail. In addition, the contact portion may be used to attach a tip structure onto the end of the beam. Examples of various tip structures and methods for mounting tip structures are described in the co-pending U.S. Patent Application entitled "Lithographically Defined Microelectronic Contact Structures" and also in co-pending U.S. Patent Application 08/819,464, which was filed March 17, 1997. In particular, **Figure 8A** shows the structure after a stage in the fabrication process of an interconnection assembly after operation 512 (without operations 502, 504, and 506 because this assembly does not utilize a redistribution layer). The structure of **Figure 8A** includes a conductive post 604a disposed in an insulating layer of the substrate 602a. The conductive post is electrically coupled to a seed layer 642a which corresponds to the seed layer 642 of **Figure 6I**. The seed layer 642a has been sputtered over a patterned photoresist layer 633a which includes an opening having a sloped side wall. The sputtered seed layer 642a is used to electrolytically plate two metal layers to create the structure shown in **Figure 8A**. The electroplating operation occurs through the patterned photoresist mask 646a which corresponds to the patterned mask 646 of **Figure 6I**. After the plating operation has occurred, each metal layer includes a base portion, such as the base portion 653a, a beam portion, such as the beam portion 653b, and a contact portion, such as the contact portion 653c. After the

electroplating operation is completed, operation 514 may be performed to remove the photoresist layers 646a and 633a and then the sputtered seed layer 642a may be removed except for the portion under the base 653a. The resulting structure may be used as a resilient contact element in an interconnect assembly without a stop structure or the stop structure may be formed by performing operation 516 as described above.

Figure 8B illustrates an array 800 of two resilient contact elements 801 and 802 on the surface of the substrate 803. **Figure 8B** is a perspective view and it will be appreciated that typically a large number of resilient contact elements may be disposed on the surface of the substrate, such as a semiconductor integrated circuit or other interconnect assemblies. The resilient contact elements shown in **Figure 8B** are similar to the type shown in **Figure 8A** in that they include a contact portion at the end of the beam structure. The beam structure, such as beam portion 653B, may be a substantially triangular shape which is attached to the base portion 653A. The contact portion 653C may serve itself as the contact tip for making contact to another contact terminal (e.g. contact terminal 411 as shown in **Figure 4**) or a tip structure as described above may be mounted onto the foot portion 653C to provide a tip structure. This structure may also be adapted for permanent connection to the contact pad (e.g. by use of solder or conductive epoxy).

Figures 9A, 9B, 9C and **9D** illustrate another method for forming a resilient contact element according to the present invention. A mold 901, which may be photolithographically formed, includes a "negative" image of at least a portion of a resilient contact element. The mold 901 is shown in **Figure 9A** prior to being used on the deformable material 903 and is positioned above the deformable material 903, which is disposed on a substrate 905 which includes wiring layer 906. The substrate 905 and wiring layer 906 is similar to the structure shown in **Figure 6E**. The deformable material 903 may be any number of materials, such as PMMA (poly methyl methacrylate), which are deformable when pressed with a mold or stamp and which can be used to receive the deposition of spring metals to form a resilient contact element and can be subsequently removed. The mold 901 includes, in the embodiment shown in **Figure 9A**, a base portion 901B and a sloped portion 901A. It will be

appreciated that other geometries may be used, including a rotated "L" shape (e.g. ¬) or a shape that will generate the curved beam portion of **Figure 2D**.

The mold 901 is pressed into the deformable material as shown in **Figure 9B**. Several pounds of pressure may be necessary (depending on the type of deformable material) in order to deform the deformable material to achieve the desired shape. This in one exemplary embodiment causes the base portion 901B to be nearly touching the surface of substrate 905, leaving a thin region of the deformable material separating this surface from the base portion 901B. The mold 901 forces the deformable material to take the positive of its negative shape as shown in **Figure 9B**. The mold 901 is then separated from the substrate 905 and deformable material 903, leaving the structure shown in **Figure 9C**. This structure is then "cleaned" to remove the thin region 903A of the deformable material which was under the base portion 901B. The structure may be cleaned with an isotopic etch which removes all exposed deformable material but does not effect the substrate 905. This etch is performed for a sufficient duration to remove all of the thin region 903A while leaving most of the remainder of the deformable material 903, including the sloped portion 903B. The structure may be cleaned to remove the thin region 903A with a plasma etch or a reactive ion etch or with a laser ablation etch. After removal of the thin region 903A, the structure is shown in **Figure 9D**, and it is ready for further processing (e.g. operations 510, 512, 514, and 516 of **Figure 5**) to create a resilient contact element using the molded deformable material.

There are numerous ways to create the mold. The mold may be formed from a silicon wafer by laser etching the surface of the wafer. A glass backing substrate with a photo-imageable material (which can be hardened) may be used with a mask to photolithographically define the mold. A silicon carbide wafer may be machined to define the mold by using electro-discharge machining techniques on the silicon carbide wafer. A negative of the mold may be formed in wax (e.g. paraffin), then sputtering a shorting layer on the surface of the negative, after which the mold is formed by electrolytically plating a metal onto the shorting layer on the wax.

The foregoing discussion has provided certain details with respect to materials and process steps. It will be appreciated that the present invention may be practiced with other types of materials and process variations. For example, in

just some of many preferred implementations, the sputtered shorting layers may use copper, gold, aluminum, titanium, titanium/tungsten or other appropriate metallization. Further, the redistribution trace 615 may use copper or gold material in creating the trace. Other materials may be employed to achieve similar results as will be appreciated by those skilled in the art. As another alternative embodiment, it will be appreciated that other methods for forming various layers may be employed. For example, processes based on electroless plating, chemical vapor deposition (CVD), or phase vapor deposition (PVD) may be utilized rather than electrolytic plating.

In the foregoing specification, the present invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader scope and spirit of the invention as set forth in the appended claims.

CLAIMS

What is claimed is:

1. A contact element in an interconnect assembly comprising:
   a base portion adapted to be adhered to a substrate;
   a beam portion connected to and extending from said base portion, said beam portion being substantially triangular in shape and being adapted to be free-standing.

2. The contact element as in claim 1, wherein said beam portion of said contact element is adapted to be resilient and a thickness of said beam portion is substantially smaller than a lateral dimension across an upper surface of said beam portion.

3. The contact element as in claim 1, wherein said contact element further comprises:
   a first layer that is electrically conductive; and
   a second layer that is mechanically resilient.

4. A contact element as in claim 1 wherein said beam portion extends from said base portion at an oblique angle relative to a surface of said substrate.

5. A contact element as in claim 1 wherein said base portion and said beam portion are lithographically formed.

6. A contact element as in claim 1 wherein said beam portion is elongate and resilient and wherein said substrate comprises an integrated circuit in an semiconductor material.

7. A contact element as in claim 1 further comprising:
   a tip portion connected to said beam portion.

8. A contact element as in claim 7 wherein said tip portion is integrally formed with said beam portion.

9. A contact element as in claim 8 wherein said base portion and said beam portion are integrally formed.

10. A contact element as in claim 1 wherein said interconnect assembly further comprises a plurality of contact elements, each having:

a respective base portion adapted to be adhered to said substrate;

a respective beam portion connected to and extending from said respective base portion, said respective beam portion being substantially triangular in shape and being adapted to be free-standing; and

wherein adjacent ones of said plurality of contact elements are spaced on said substrate at a pitch in a range of approximately 2.5 to 2000 microns.

11. A contact element as in claim 10 wherein said pitch is less than approximately 500 microns.

12. A contact element as in claim 10 wherein said substrate comprises an integrated circuit in a semiconductor material.

13. A contact element as in claim 1 wherein said beam portion extends from an end of said base portion at an oblique angle relative to a surface of said substrate and wherein said base portion is parallel to said surface.

14. A contact element as in claim 1 further comprising:

a tip structure which is fabricated separately from said beam portion and which is mounted onto said beam portion.

15. A method of forming a contact element, said method comprising:

forming a base portion to adhere to a substrate of an electrical assembly;

forming a beam portion connected to said base portion, said beam portion extending from said base portion and being substantially triangular in shape and being adapted to be free-standing.

16. A method as in claim 15 wherein said beam portion is resilient and elongate.

17. A method as in claim 16 wherein said base portion and said beam portion are formed lithographically.

18. A method as in claim 17 wherein said base portion and said beam portion are integrally formed in one operation.

19. A method as in claim 17 wherein said base portion and said beam portion are formed by:

applying a first masking layer;

creating a first opening in said first masking layer, said first opening having a first region and a second region, said second region comprising a sloped wall;

depositing a conductive material into said first opening.

20. A method as in claim 19 further comprising:

applying a second masking layer after creating said first opening;

creating a second opening in said second masking layer, said second opening defining said substantially triangular shape.

21. A method as in claim 20 wherein said depositing said conductive material comprises:

plating said conductive material in said first opening through said second opening.

22. A method as in claim 19 wherein said conductive material deposited in said first region forms said base portion and said conductive material deposited in said second region forms said beam portion, and wherein said beam portion extends from an end of said base portion at an oblique angle relative to a surface of said substrate.

23. A contact element in an interconnect assembly comprising:

a base portion adapted to be adhered to a substrate;
a beam portion connected to and extending from said base portion, said beam portion being adapted to be free-standing and having a beam geometry which substantially evenly distributes stress throughout the beam when deflected.

24. The contact element as in claim 23, wherein said beam portion of said contact element is adapted to be resilient and a thickness of said beam portion is substantially smaller than a lateral dimension across an upper surface of said beam portion.

25. The contact element as in claim 23, wherein said contact element further comprises:
a first layer that is electrically conductive; and
a second layer that is mechanically resilient.

26. A contact element as in claim 23 wherein said beam portion extends from said base portion at an oblique angle relative to a surface of said substrate and said beam portion has a substantially triangular shape.

27. A contact element as in claim 23 wherein said base portion and said beam portion are lithographically formed.

28. A contact element as in claim 23 wherein said beam portion is elongate and resilient and wherein said substrate comprises an integrated circuit in an semiconductor material.

29. A contact element as in claim 23 further comprising:
a tip portion connected to said beam portion.

30. A contact element as in claim 29 wherein said tip portion is integrally formed with said beam portion.

31. A contact element as in claim 30 wherein said base portion and said beam portion are integrally formed.

32. A contact element as in claim 23 wherein said interconnect assembly further comprises a plurality of contact elements, each having:

a respective base portion adapted to be adhered to said substrate;

a respective beam portion connected to and extending from said respective base portion, said respective beam portion having said beam geometry and being adapted to be free-standing; and

wherein adjacent ones of said plurality of contact elements are spaced on said substrate at a pitch in a range of approximately 2.5 to 2000 microns.

33. A contact element as in claim 32 wherein said pitch is less than approximately 500 microns.

34. A contact element as in claim 32 wherein said substrate comprises an integrated circuit in a semiconductor material.

35. A contact element as in claim 23 wherein said beam portion extends from an end of said base portion at an oblique angle relative to a surface of said substrate and wherein said base portion is parallel to said surface.

36. A contact element as in claim 23 further comprising:

a tip structure which is fabricated separately from said beam portion and which is mounted onto said beam portion.

37. A method of forming a contact element, said method comprising:

forming a base portion to adhere to a substrate of an electrical assembly;

forming a beam portion connected to said base portion, said beam portion extending from said base portion and being adapted to be free-standing and having a beam geometry which substantially evenly distributes stress throughout the beam when deflected.

38. A method as in claim 37 wherein said beam portion is resilient and elongate and has a substantially triangular shape.

39. A method as in claim 38 wherein said base portion and said beam portion are formed lithographically.

40. A method as in claim 39 wherein said base portion and said beam portion are integrally formed in one operation.

41. A method as in claim 39 wherein said base portion and said beam portion are formed by:

applying a first masking layer;

creating a first opening in said first masking layer, said first opening having a first region and a second region, said second region comprising a sloped wall;

depositing a conductive material into said first opening.

42. A method as in claim 41 further comprising:

applying a second masking layer after creating said first opening;

creating a second opening in said second masking layer, said second opening defining said substantially triangular shape.

43. A method as in claim 42 wherein said depositing said conductive material comprises:

plating said conductive material in said first opening through said second opening.

44. A method as in claim 41 wherein said conductive material deposited in said first region forms said base portion and said conductive material deposited in said second region forms said beam portion, and wherein said beam portion extends from an end of said base portion at an oblique angle relative to a surface of said substrate.

45. A contact element in an interconnect assembly comprising:

a base portion adapted to be adhered to a substrate;

a beam portion connected to and extending from said base portion, said beam portion being adapted to be free-standing and wherein a geometry of said beam is designed to produce a substantially optimized stress parameter given a desired size constraint of said beam portion and a desired spring constant for said contact element.

46. The contact element as in claim 45, wherein said beam portion of said contact element is adapted to be resilient and a thickness of said beam portion is substantially smaller than a lateral dimension across an upper surface of said beam portion.

47. The contact element as in claim 45, wherein said contact element further comprises:

a first layer that is electrically conductive; and

a second layer that is mechanically resilient.

48. A contact element as in claim 45 wherein said beam portion extends from said base portion at an oblique angle relative to a surface of said substrate and said beam portion has a substantially triangular shape.

49. A contact element as in claim 45 wherein said contact element is resilient and wherein said base portion and said beam portion are lithographically formed separately and wherein said geometry is selected to improve performance over a cantilever beam having a substantially constant cross-sectional area.

50. A contact element as in claim 45 wherein said beam portion is elongate and resilient and wherein said substrate comprises an integrated circuit in an semiconductor material.

51. A contact element as in claim 45 further comprising:

a tip portion connected to said beam portion.

52. A contact element as in claim 51 wherein said tip portion is integrally formed with said beam portion.

53. A contact element as in claim 52 wherein said base portion and said beam portion are integrally formed.

54. A contact element as in claim 45 wherein said interconnect assembly further comprises a plurality of contact elements, each having:

a respective base portion adapted to be adhered to said substrate;

a respective beam portion connected to and extending from said respective base portion, said respective beam portion having said beam geometry and being adapted to be free-standing; and

wherein adjacent ones of said plurality of contact elements are spaced on said substrate at a pitch in a range of approximately 2.5 to 2000 microns.

55. A contact element as in claim 54 wherein said pitch is less than approximately 500 microns.

56. A contact element as in claim 54 wherein said substrate comprises an integrated circuit in a semiconductor material.

57. A contact element as in claim 45 wherein said beam portion extends from an end of said base portion at an oblique angle relative to a surface of said substrate and wherein said base portion is parallel to said surface.

58. A contact element as in claim 45 further comprising:

a tip structure which is fabricated separately from said beam portion and which is mounted onto said beam portion.

59. A method of forming a resilient contact element, said method comprising:

forming a base portion to adhere to a substrate of an electrical assembly;

forming a beam portion connected to said base portion, said beam portion extending from said base portion and being adapted to be free-

standing and having a beam geometry which is designed to produce a substantially optimized stress parameter given a desired size constraint of said beam portion and a desired spring constant for said resilient contact element.

60. A method as in claim 59 wherein said beam portion is resilient and elongate and has a substantially triangular shape.

61. A method as in claim 60 wherein said base portion and said beam portion are separately formed lithographically and wherein said beam geometry is selected to improve performance over a cantilever beam having a substantially constant cross-sectional area.

62. A method as in claim 60 wherein said base portion and said beam portion are integrally formed in one operation.

63. A method as in claim 61 wherein said base portion and said beam portion are formed by:

applying a first masking layer;

creating a first opening in said first masking layer, said first opening having a first region and a second region, said second region comprising a sloped wall;

depositing a conductive material into said first opening.

64. A method as in claim 63 further comprising:

applying a second masking layer after creating said first opening;

creating a second opening in said second masking layer, said second opening defining said substantially triangular shape.

65. A method as in claim 64 wherein said depositing said conductive material comprises:

plating said conductive material in said first opening through said second opening.

66. A method as in claim 63 wherein said conductive material deposited in said first region forms said base portion and said conductive material deposited in said second region forms said beam portion, and wherein said beam portion extends from an end of said base portion at an oblique angle relative to a surface of said substrate.

67. An interconnect assembly comprising:
a substrate;
a contact element disposed on said substrate, a first portion of said contact element adapted to be free-standing and further adapted to be capable of moving from a first position to a second position when a force is applied to said first portion of said contact element; and
a stop structure disposed on a second portion of said contact element, said stop structure defining said second position.

68. The interconnect assembly as in claim 67, wherein a plurality of said contact elements are disposed on said substrate, said contact elements disposed in a pitch having a range of about 2.5 microns to 2000 microns.

69. The interconnect assembly as in claim 67, wherein said substrate has a bond pad connected to a microelectronic device, said contact element disposed on said bond pad.

70. The interconnect assembly as in claim 67, wherein said substrate has a re-distributed conductor connected to a microelectronic device, said contact element disposed on said re-distributed conductor.

71. The interconnect assembly as in claim 67, wherein said substrate has a bond pad connected to a test equipment, said contact element disposed on said bond pad.

72. The interconnect assembly as in claim 67, wherein said contact element is resilient and wherein said stop structure presses against said second portion with said force when said force is applied to said first portion.

73. The interconnect assembly as in claim 67, wherein said contact element comprises at least one metal layer.

74. The interconnect assembly as in claim 67, wherein said contact element comprises a first metal layer and a second metal layer, said first metal layer providing said contact element with resiliency and said second metal layer providing electrical conductivity for said contact element.

75. The interconnect assembly as in claim 67, wherein said contact element is an elongate resilient contact element.

76. The interconnect assembly as in claim 67, wherein said first portion of said contact element is sloped relative to a surface of said substrate such that one end of said first portion of said contact element is at a height above said surface of said substrate.

77. The interconnect assembly as in claim 67, wherein a portion of said first portion of said contact element protrudes at a height from a surface of said stop structure.

78. The interconnect assembly as in claim 77, wherein said height in which said contact element protrudes from said surface of said stop structure is a predetermined height.

79. The interconnect assembly as in claim 67, wherein said substrate comprises an integrated circuit in a semiconductor material, and wherein said force is applied when another contact element is brought into mechanical and electrical contact with said contact element.

80. The interconnect assembly as in claim 67, wherein said contact element is a resilient contact element and wherein said force is applied when another contact element is brought into mechanical and electrical contact with said contact element and wherein said force causes said resilient contact element to flex from said first

position to said second position and wherein said stop structure defines said second position which defines a maximum flexing of said resilient contact element.

81. The interconnect assembly as in claim 67, wherein said first portion of said contact element has substantially a triangular shape and a third portion of said contact element being a point of said triangular shape.

82. The interconnect assembly as in claim 67, wherein said stop structure has a vertical height that is less than a vertical height of a shortest contact element that is statistically likely to exist.

83. A method of forming an interconnect assembly, said method comprising:

disposing a contact element on a substrate, a first portion of said contact element being free-standing and being capable of moving from a first position to a second position when a force is applied to said first portion of said contact element; and

disposing a stop structure on a second portion of said contact element, said stop structure defining said second position.

84. The method as in claim 83, wherein disposing said contact element on said substrate includes disposing another contact element on said substrate in a fine pitch.

85. The method as in claim 83, wherein said contact element is free-standing and resilient.

86. The method as in claim 83, wherein disposing said contact element further comprises:

applying a first masking layer on said substrate;

forming in said first masking layer, an opening extending into said first masking layer, said opening having a tapered wall; and

depositing a metal layer on said tapered wall of said opening of said first masking layer.

87. The method as in claim 86, wherein said tapered wall is tapered using at least one technique of tapering by using a gradual scale, tapering by reflowing, tapering by controlled exposure, tapering by varying a mask distance or tapering by multiple exposures.

88. The method as in claim 86, wherein after forming said tapered wall, the method further comprises:

placing a mask pattern over said first masking layer, said mask pattern having a pattern substantially triangular in shape; and

depositing said metal layer in said opening of said first masking layer in said substantially triangular shape according to said mask pattern.

89. The method as in claim 86, wherein depositing said metal layer includes using one of a sputtering deposition process, an electroplating process, a chemical vapor deposition process and an electroless plating process.

90. The method as in claim 86, wherein depositing said metal layer includes:

depositing a first metal layer, said first metal layer selected for its resilient property; and

depositing a second metal layer, said second metal layer selected for its electrical conducting property.

91. The method as in claim 86, further comprising:

removing a portion of said first masking layer as to allow said contact element to be free-standing; and

applying an additional layer as to cover said second portion of said contact element.

92. The method as in claim 91, further comprising:

planarizing said first masking layer to form said stop structure, said stop structure having a vertical height less than a vertical height of a shortest contact element that exists.

93. The method as in claim 86, further comprising:

removing said first masking layer;

applying a second layer over said second portion of said contact element and allowing said first portion of said contact element to be free-standing.

94. The method as in claim 93, further comprising:

planarizing said second layer to form said stop structure, said stop structure having a vertical height less than a vertical height of a shortest contact element.

95. The method as in claim 83, wherein said contact element is a resilient contact element which is free-standing and wherein said force is applied when another contact element is brought into mechanical and electrical contact with said contact element and wherein said force causes said resilient contact element to flex from said first position to said second position and wherein said stop structure defines said second position which defines a maximum flexing of said resilient contact element.

96. The method as in claim 83, wherein said contact element is a resilient contact element which is free-standing and wherein said stop structure presses against said second portion with said force when said force is applied to said first portion and wherein said force is applied when another contact element is brought into mechanical and electrical contact with said contact element.

97. An electrical system comprising:

a first substrate having a first contact element;

a second substrate;

at least one second contact element disposed on said second substrate, a first portion of said second contact element adapted to be free-standing and further adapted to be capable of moving from a first position to a second position when a force is applied to said first portion of said second contact element by said first contact element; and

a stop structure disposed on a second portion of said second contact element, said stop structure defining said second position.

98. The electrical system as in claim 97, wherein said second substrate has a bond pad connected to a microelectronic device, said second portion of said second contact element disposed on said bond pad, and said first substrate is one of (1) a test probe assembly having said first contact element to make contact with said second contact element and (2) a package having said first contact element to house said microelectronic device during use of said microelectronic device.

99. A method for forming a freestanding, elongate resilient contact element, said method comprising:

depressing a mold into a deformable material, said mold determining a shape of at least a portion of said freestanding, elongate resilient contact element;

forming at least said portion of said freestanding, elongate resilient contact element on said deformable material.

100. A method as in claim 99 wherein said forming comprises depositing a conductive material on said deformable material after said deformable material has been deformed with said mold.

101. A method as in claim 100 wherein said mold comprises a plurality of shapes for a corresponding plurality of portions of freestanding, elongate resilient contact elements.

102. A method as in claim 101 further comprising:

removing said deformable material after depositing said conductive material.

103. A method as in claim 102 wherein said freestanding, elongate resilient elements are disposed on corresponding electrical interconnect pads on a substrate.

104. A method as in claim 103 wherein said substrate comprises a semiconductor integrated circuit.

105. A lithographically formed resilient contact element having a curved beam portion which extends upwardly from a substrate and which is lithographically defined.

106. A lithographically formed resilient contact element as in claim 105 further comprising:

a base portion attached mechanically to said substrate and electrically coupled to an electrical interconnection terminal on said substrate, and wherein said resilient contact element is freestanding when released after being initially formed.

107. A lithographically defined resilient contact element as in claim 106 wherein a curve of said curved beam portion extends upwardly away from said substrate and said curve is lithographically defined by a curved slope in a sacrificial layer which is removed to release said resilient contact element.

108. A lithographically defined resilient contact element as in claim 106 further comprising a sacrificial layer which defines a curve of said curved beam portion.

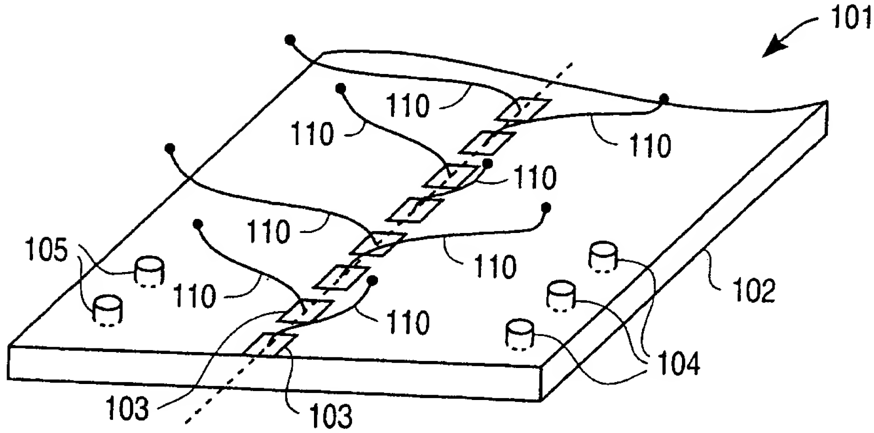
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FIG. 1A

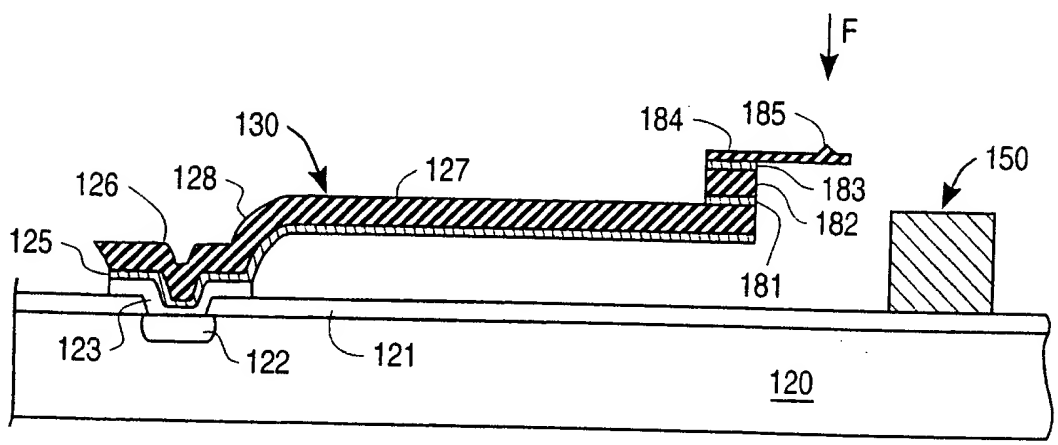
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FIG. 1B

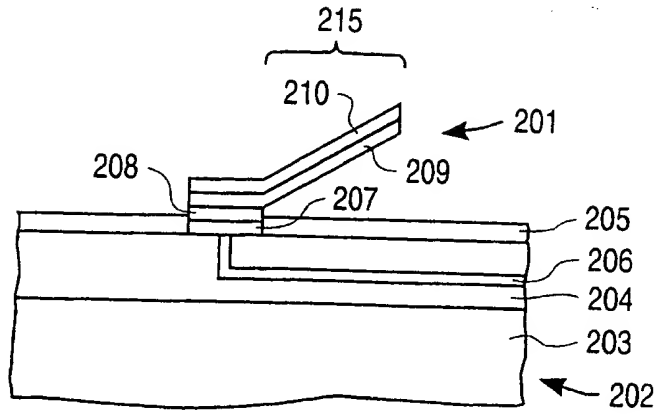


FIG. 2A

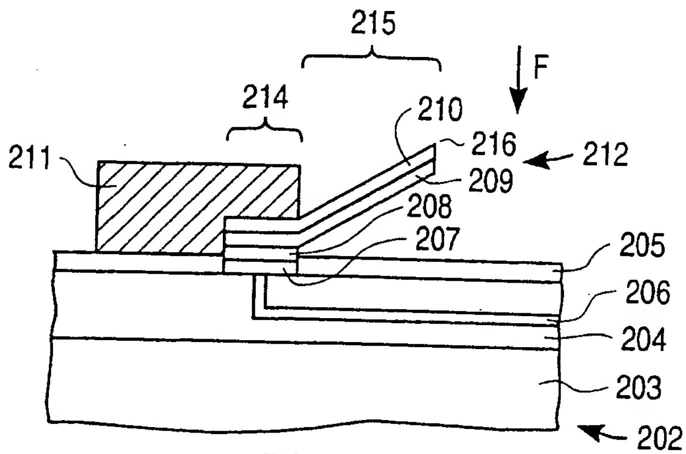


FIG. 2B

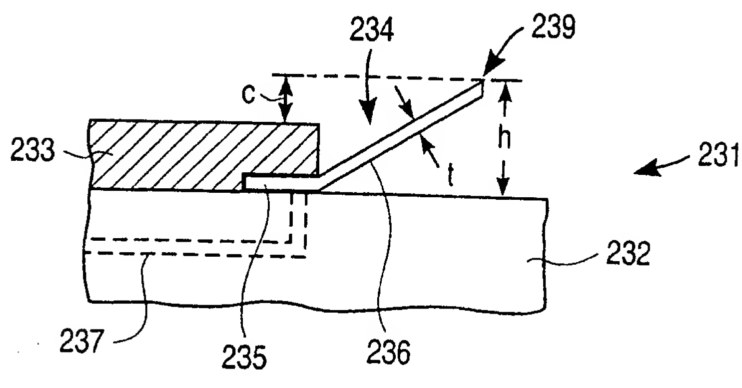


FIG. 2C

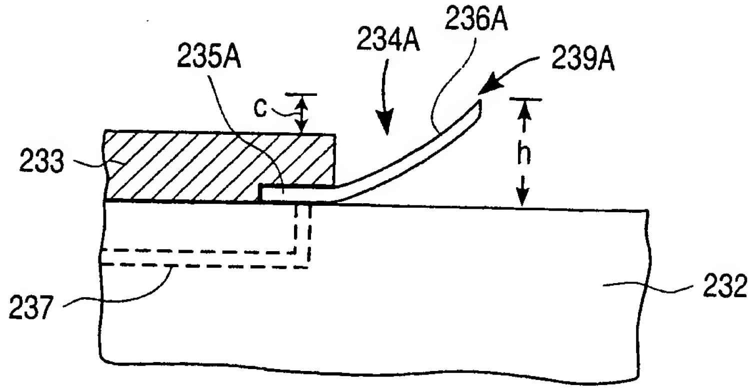


FIG. 2D

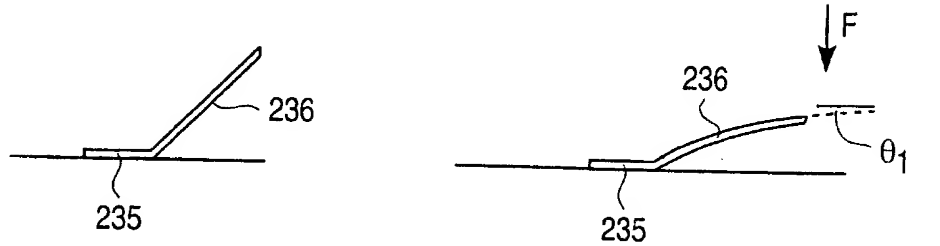


FIG. 2E

FIG. 2F

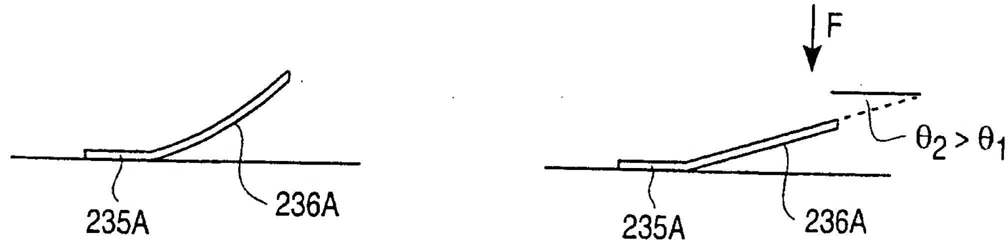


FIG. 2G

FIG. 2H

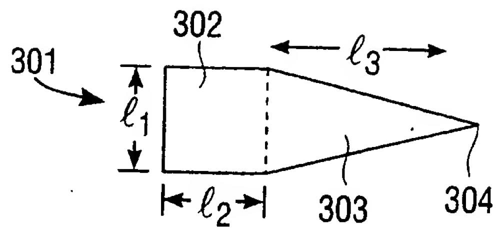


FIG. 3A

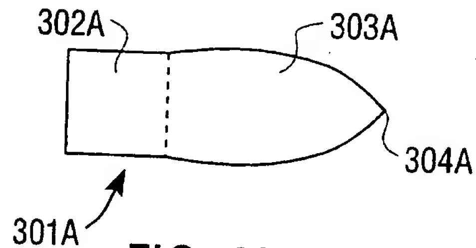


FIG. 3B

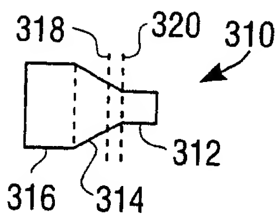


FIG. 3C

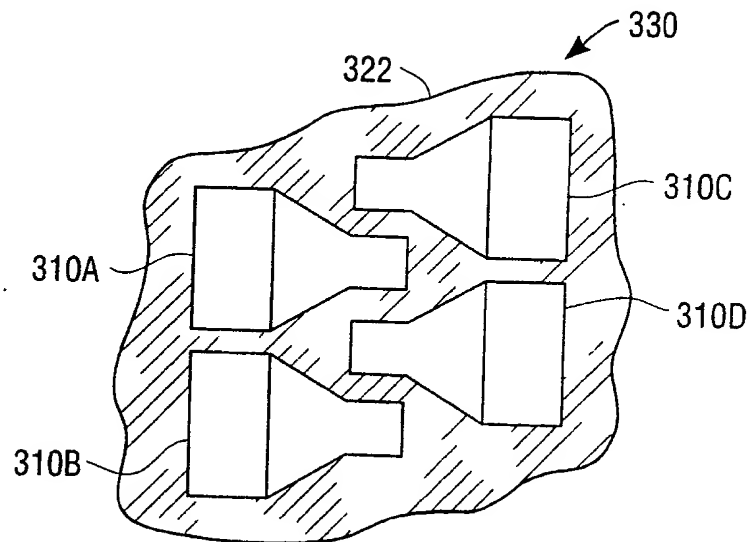


FIG. 3D

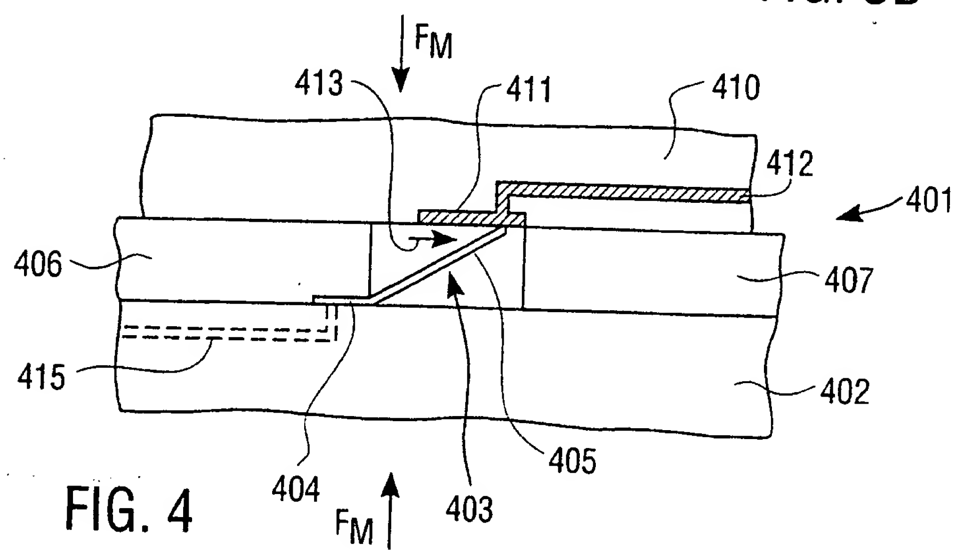


FIG. 4

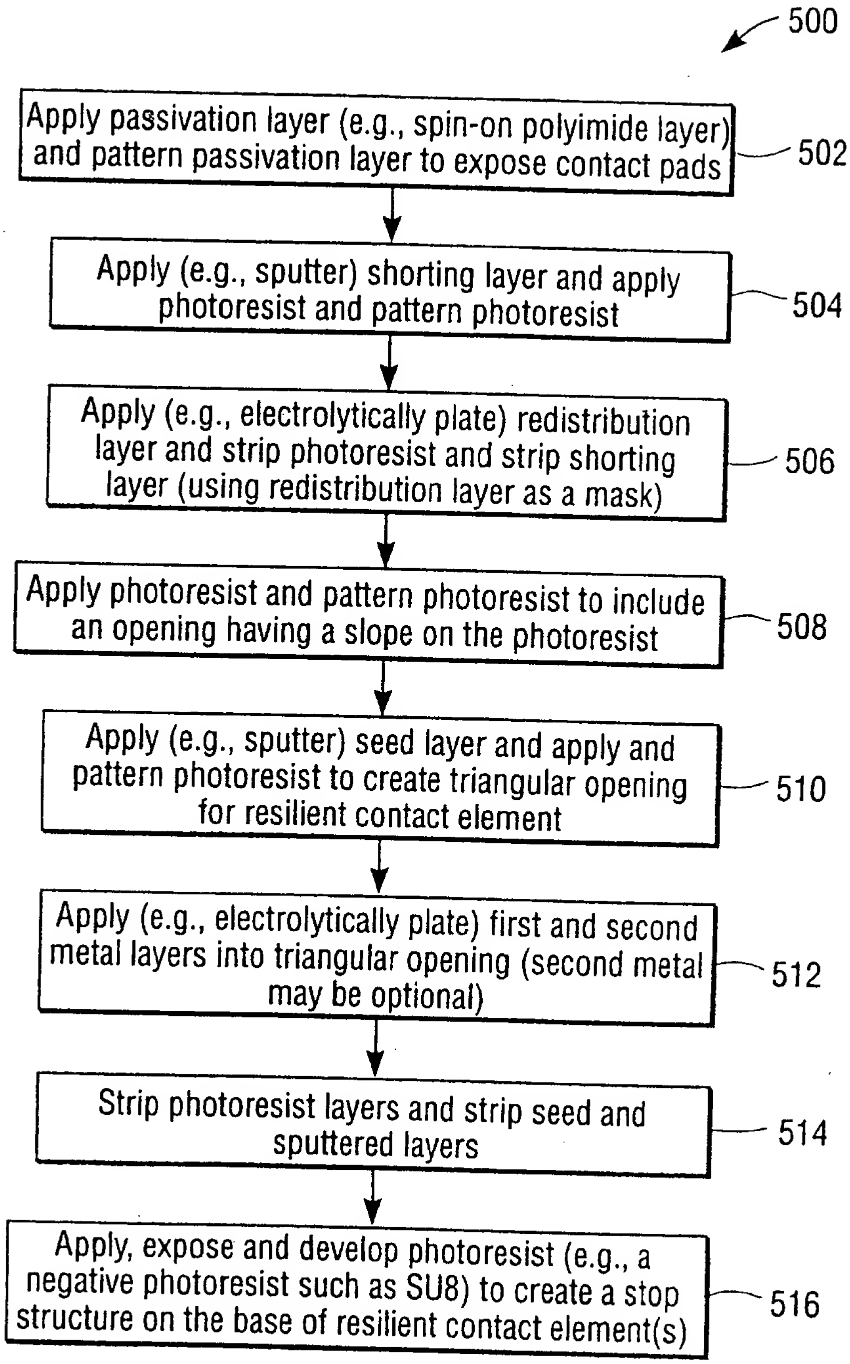

500
Apply passivation layer (e.g., spin-on polyimide layer) and pattern passivation layer to expose contact pads
502
Apply (e.g., sputter) shorting layer and apply photoresist and pattern photoresist
504
Apply (e.g., electrolytically plate) redistribution layer and strip photoresist and strip shorting layer (using redistribution layer as a mask)
506
Apply photoresist and pattern photoresist to include an opening having a slope on the photoresist
508
Apply (e.g., sputter) seed layer and apply and pattern photoresist to create triangular opening for resilient contact element
510
Apply (e.g., electrolytically plate) first and second metal layers into triangular opening (second metal may be optional)
512
Strip photoresist layers and strip seed and sputtered layers
514
Apply, expose and develop photoresist (e.g., a negative photoresist such as SU8) to create a stop structure on the base of resilient contact element(s)
516

FIG. 5

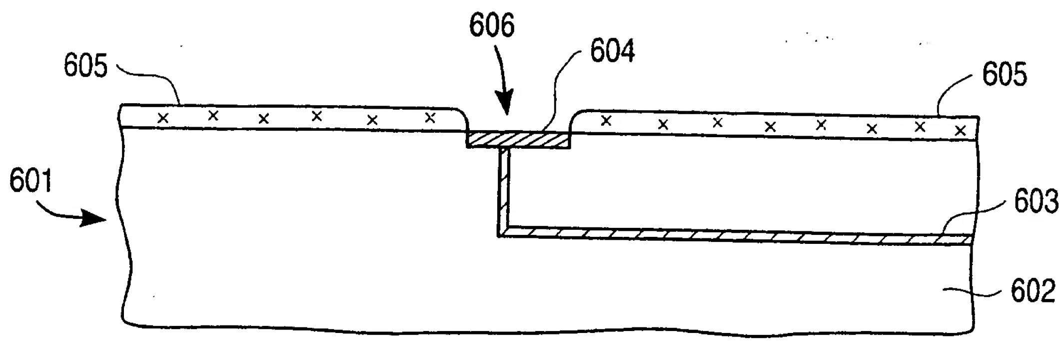


FIG. 6A

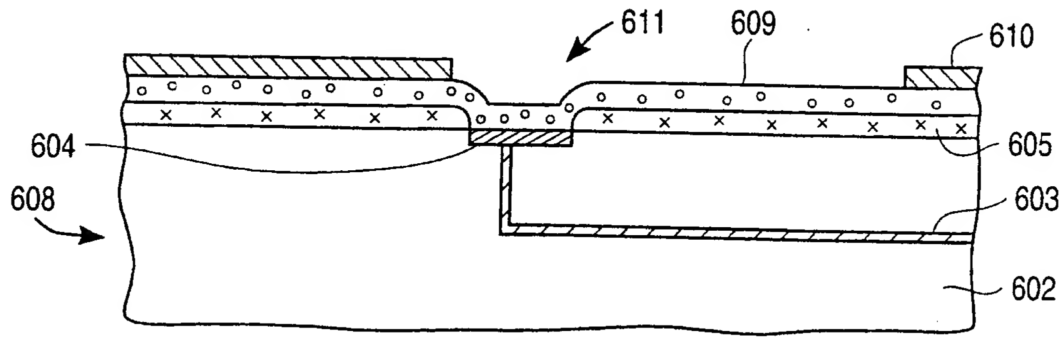


FIG. 6B

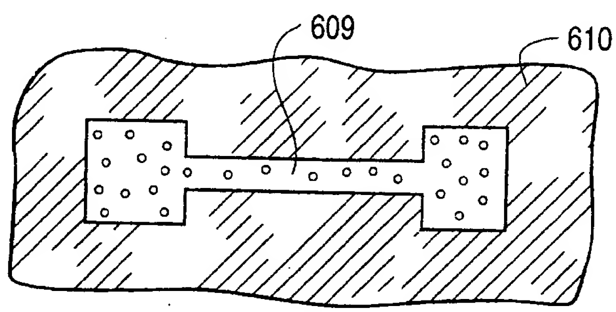


FIG. 6C

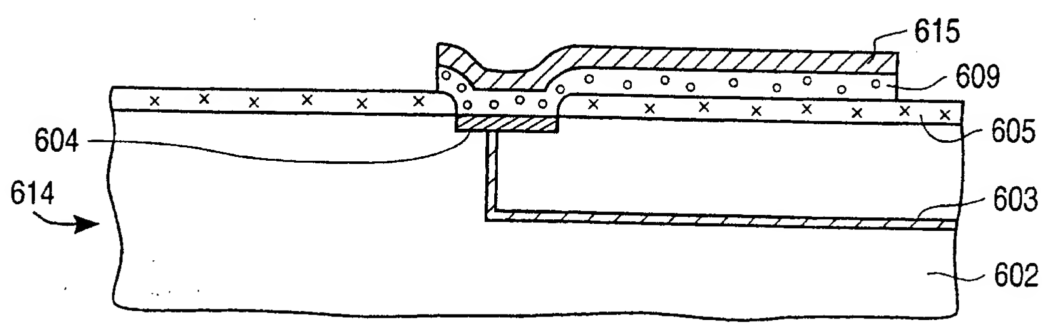


FIG. 6D

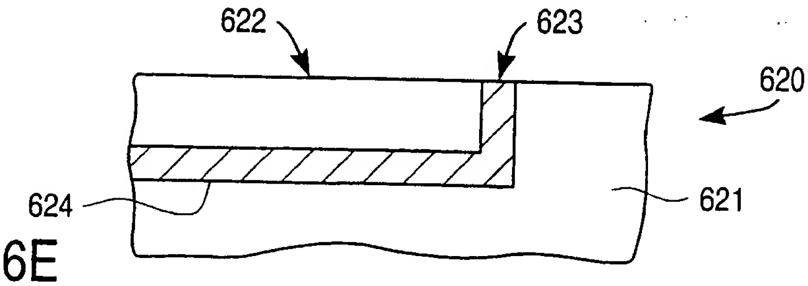


FIG. 6E

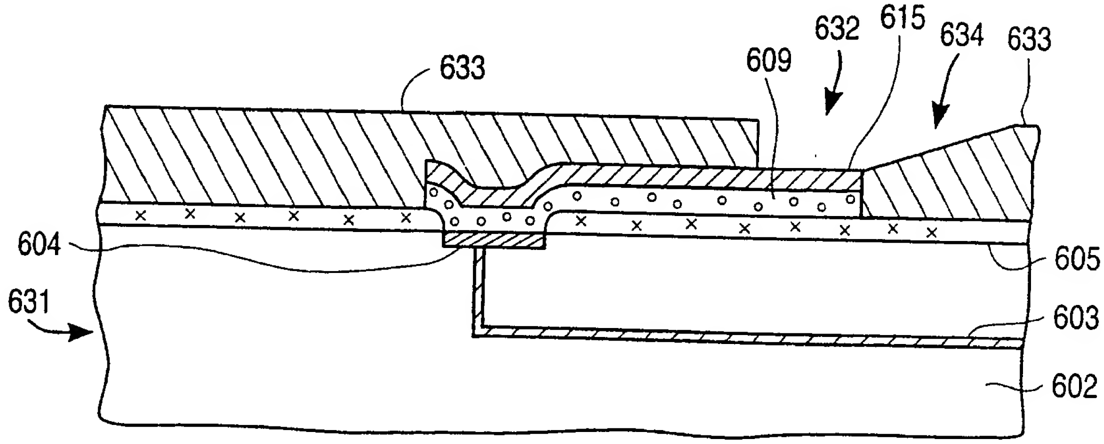


FIG. 6F

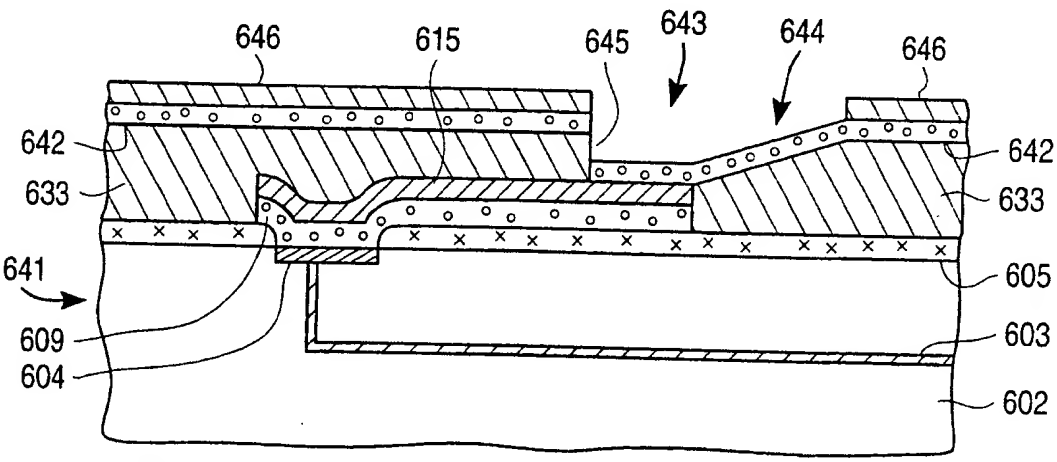


FIG. 6G

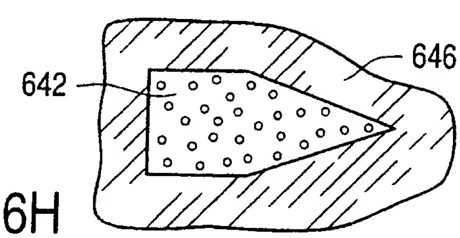


FIG. 6H

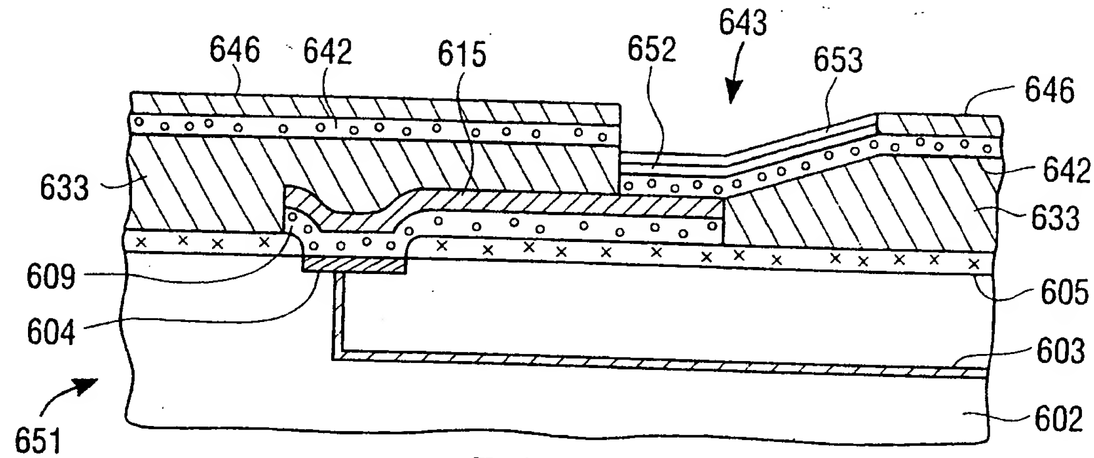


FIG. 6I

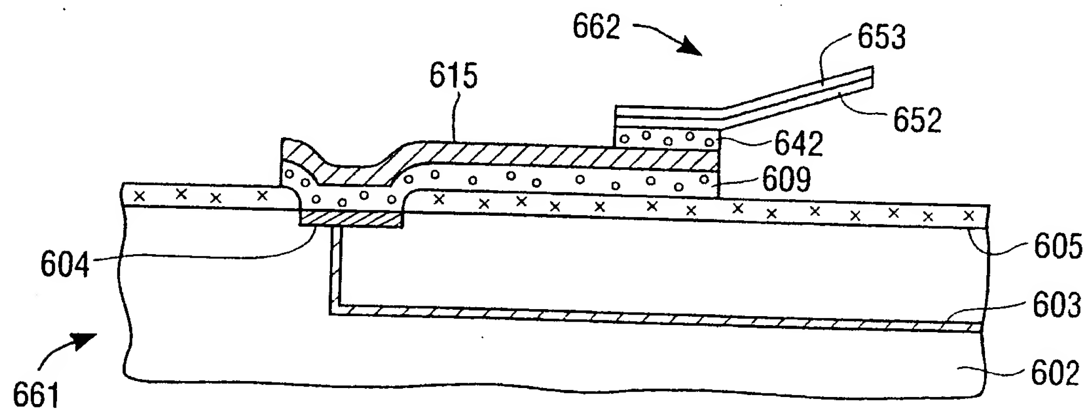


FIG. 6J

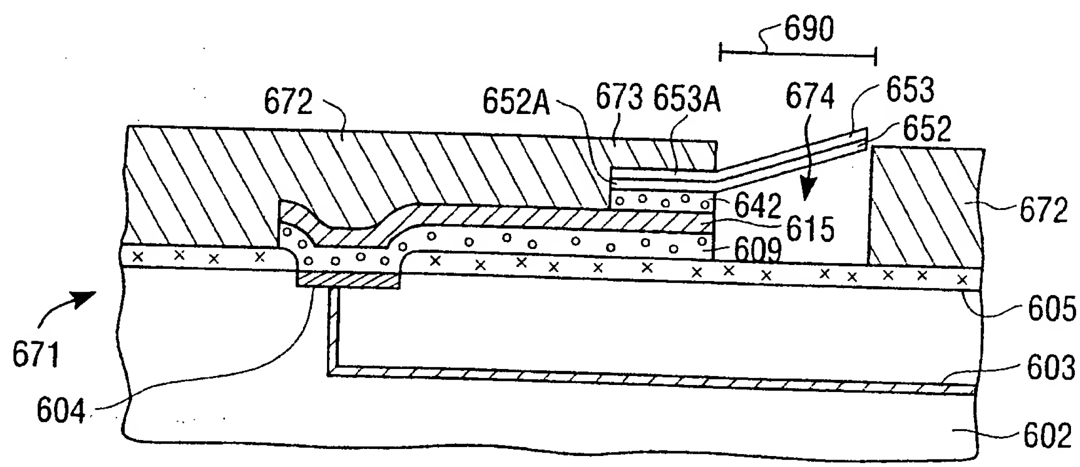


FIG. 6K

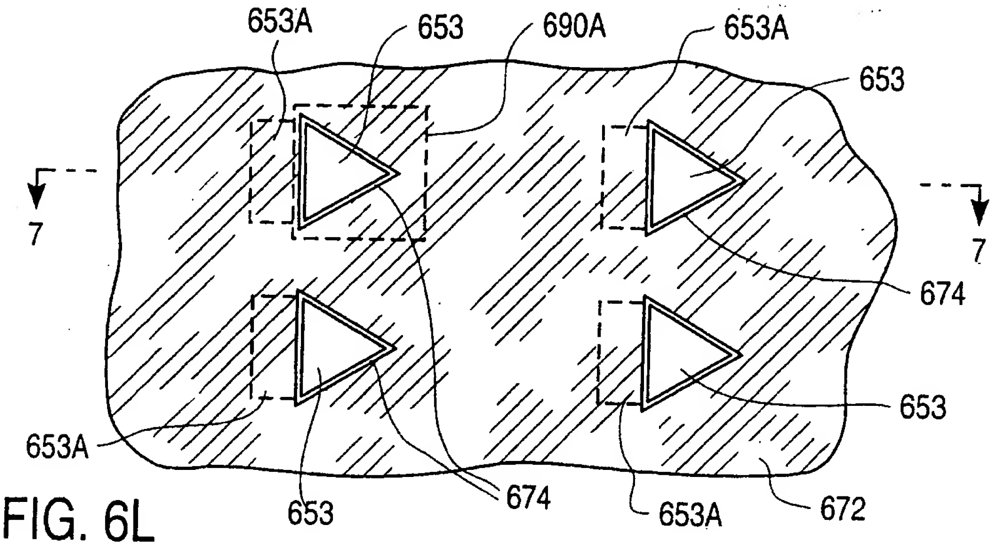


FIG. 6L

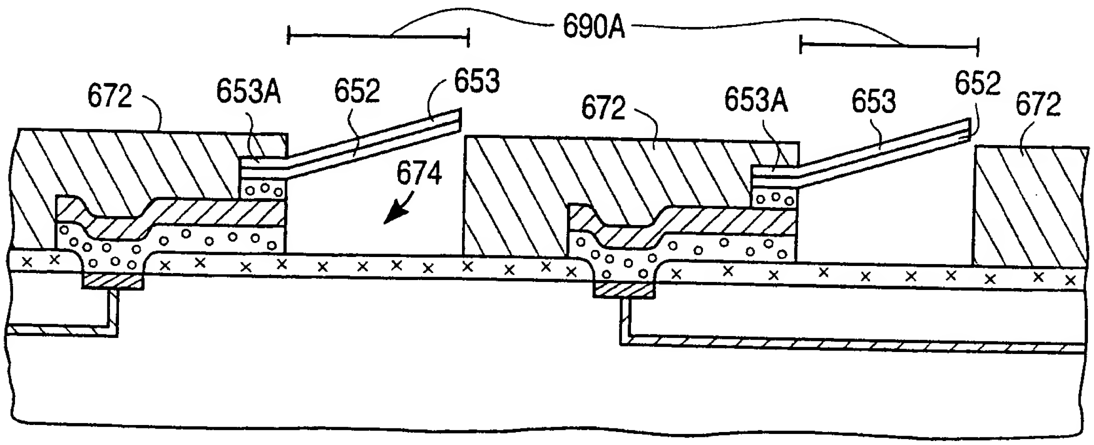


FIG. 7A

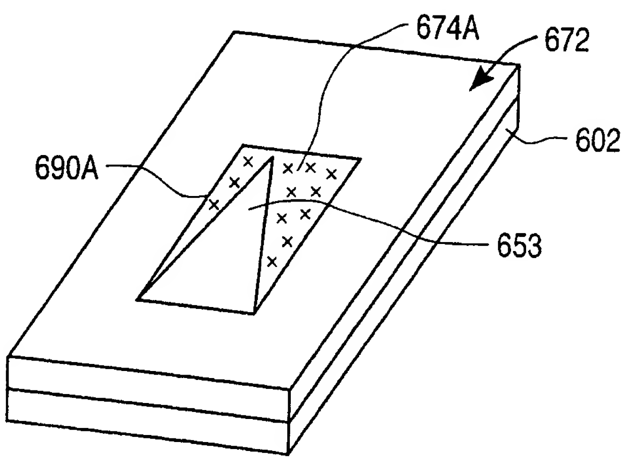
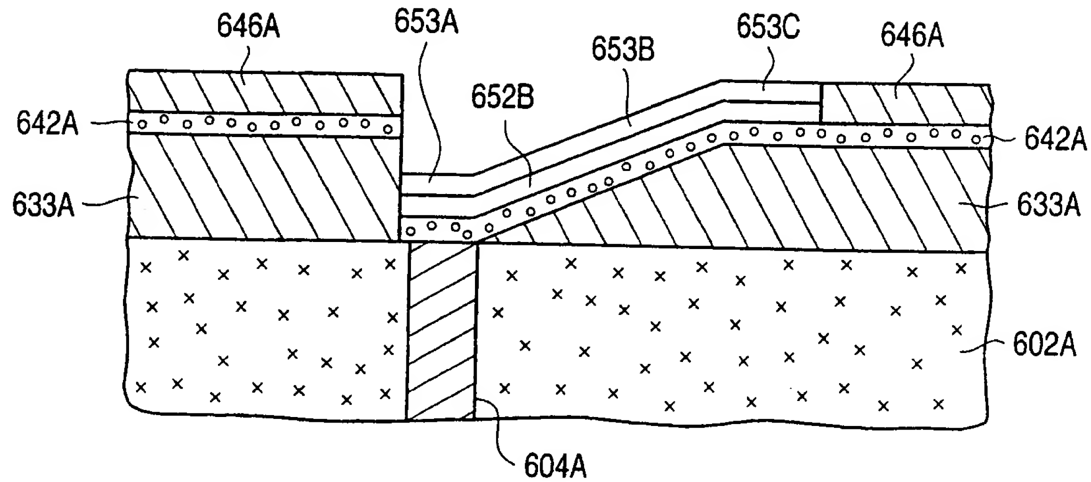


FIG. 7B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604A

FIG. 8A

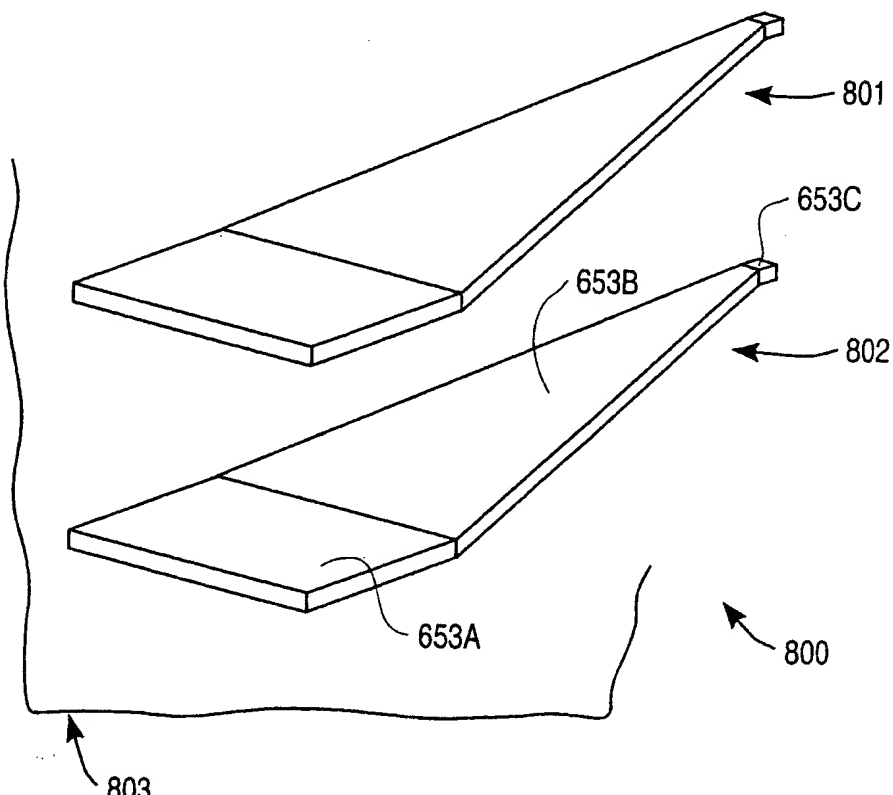
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FIG. 8B

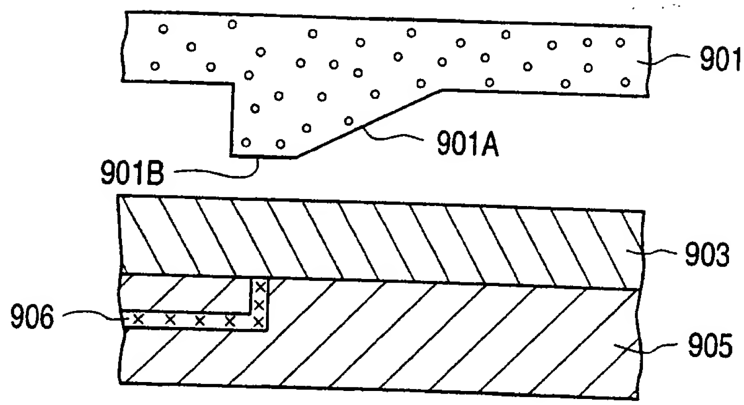

FIG. 9A

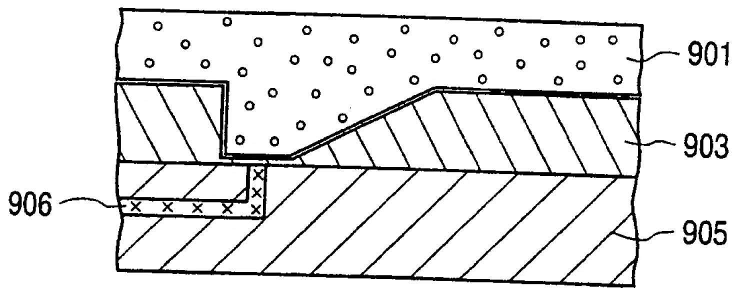

FIG. 9B

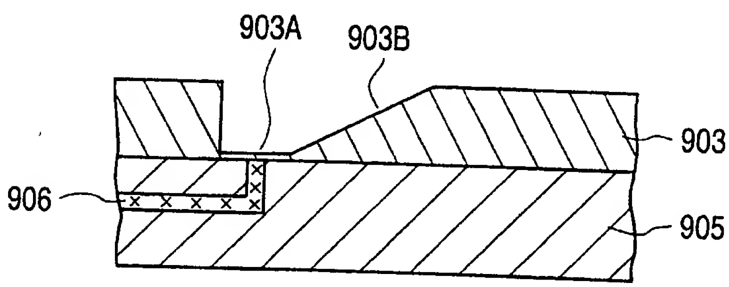

FIG. 9C

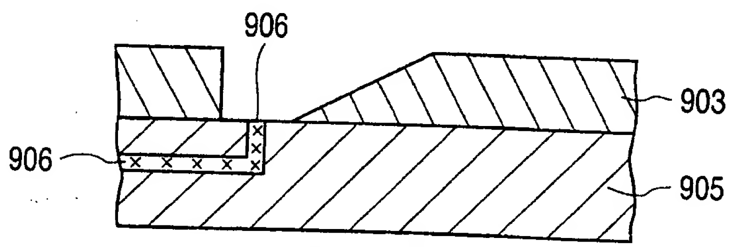

FIG. 9D